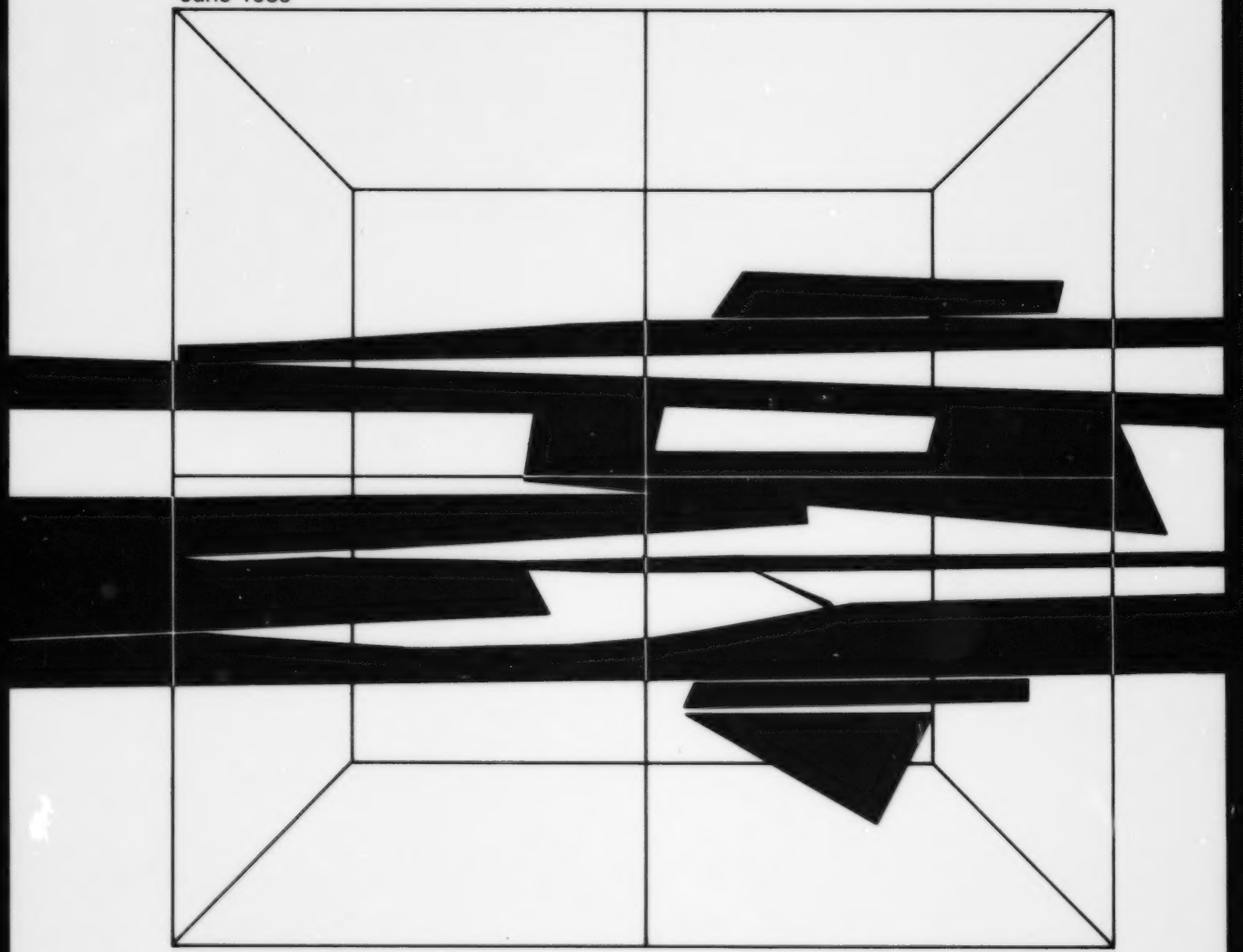
Environmental Assessment of the Canadian Textile Industry

Report EPS 5/TX/1
June 1989



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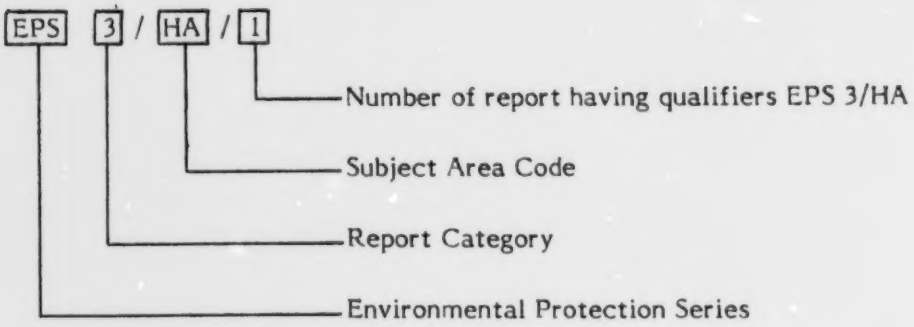
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ENVIRONMENTAL ASSESSMENT OF THE CANADIAN TEXTILE INDUSTRY

E.C. Chen
Chemical Industries Division
Industrial Programs Branch

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ABSTRACT

The purpose of this report is to assess the environmental problems associated with discharges from Canadian textile mills based on information obtained from surveys carried out in 1973/74, 1981/82 and 1985/86, respectively.

About 55% of the textile mills are located in Quebec and 40% in Ontario. Approximately 20% of the mills use wet processing and about half of these wet textile mills belong to the woven fabric and knit fabric dyeing and finishing subcategories. More than 80% of the wet processing mills discharge their effluents to a municipal system; about half of those discharging directly to a natural watercourse have wastewater treatment facilities.

All mills included in the surveys and discharging to a municipal system met the BOD and TSS limits set by local municipal sewer by-laws. Mills with secondary wastewater treatment had loadings of BOD and TSS within or close to the U.S. EPA BPT limits as well as Environment Canada's 1978 Proposed Guidelines. Most of the mills had an effluent pH value within the range of 6 to 9.

Metal pollutants expected to be found in textile mill effluents are zinc, copper, chromium, lead and nickel; the effluent concentration of these metals individually are all less than 1 mg/L, the discharge limit set by most of the local municipal sewer by-laws. Possible organic priority pollutants in textile mill effluents, at the ppb levels, are substituted benzenes, naphthalene, phenol, substituted phenols, chloroethylenes, chloroethanes and phthalates.

Effluents from mills without wastewater treatment or with only primary treatment would be coloured and toxic to fish. However, mills with a well-operated biological treatment system can produce an effluent non-lethal to fish and with no apparent colour. A well-operated biological treatment system can also reduce the effluent surfactant concentration to an insignificant level.

Wastes other than wastewaters and sludges produced by textile mills include waste fabric, waste fibres, waste oils and latex wastes; the latter two types of wastes are considered to be hazardous.

Most of the textile mills surveyed have some controls of the particulate/fibre and dust emissions. However, very few have installed control devices for solvent vapours, oil mists and odour.

RÉSUMÉ

L'objet du présent rapport est d'évaluer les problèmes environnementaux causés par les effluents d'usines textiles canadiennes, d'après l'information recueillie lors d'études effectuées respectivement en 1973/74, 1980/82 et 1985/86.

À peu près 55% des usines textiles sont situées au Québec, et 40% en Ontario. Environ 20% des usines utilisent les traitements au mouillé, et environ la moitié de ces usines font partie des sous-secteurs de la teinture et d'apprêt de tissu chaîne et trame et de tissu tricot. Plus de 80% des usines utilisant le traitement au mouillé déversent leurs effluents dans un réseau municipal; environ la moitié de celles qui déversent directement leurs effluents dans une formation aquifère naturelle possèdent des installations d'épuration des eaux usées.

Toutes les usines étudiées, qui déversaient leurs effluents dans un réseau municipal, respectaient les limites de DBO et de SST, fixées par les règlements municipaux sur les égouts. Les usines pratiquant le traitement secondaire des eaux usées accusaient des charges de DBO et de SST inférieures ou presque égales aux limites U.S. EPA BPT, et conformes aux Directives proposées par le SPE en 1978. L'effluent de la plupart des usines avait un pH variant de 6 à 9.

Les polluants métalliques que l'on peut retrouver dans les effluents d'usines textiles sont les suivants : zinc, cuivre, chrome, plomb et nickel; la concentration individuelle de ces métaux dans l'effluent est inférieure à 1 mg/L, limite imposée aux déversements par la plupart des règlements municipaux sur les égouts. Parmi les polluants organiques prioritaires qu'on pourrait trouver dans les effluents d'usines textiles, en p.p. milliard, on peut citer les dérivés de substitution du benzène, le naphtalène, le phénol, les dérivés de substitution du phénol, les chloréthylènes, les chloréthanes et les phtalates.

Les effluents d'usines sans système de traitement des eaux usées ou n'utilisant que le traitement primaire peuvent être colorés et toxiques pour les poissons. Par contre, les usines bénéficiant d'un système de traitement biologique, exploité de façon efficace, peuvent produire un effluent non létal pour les poissons et sans couleur apparente. Un tel système permet également de réduire la concentration de surfactif dans l'effluent à un niveau négligeable.

Parmi les déchets, autres que les eaux usées et les boues, produits par les usines textiles, on peut citer les tissus, les fibres, les huiles et le latex résiduaires; les deux derniers types de déchets sont considérés comme étant dangereux.

La plupart des usines textiles de l'enquête possédaient des moyens de décontamination pour les émissions de particules solides/fibres et de poussières. Par contre, très peu d'entre elles étaient pourvues de dispositifs permettant d'éliminer les vapeurs de solvants, les brouillards d'huiles et les odeurs.

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Two of the surveys (i.e., the 1973/74 survey and the 1981/82 survey) were carried out by the predecessor of the Renewable Resources, Extraction and Processing Division which was then known as the Paper, Fibre and Allied Products Division of the Water Pollution Control Directorate.

General guidance on the project development was provided by D. Wayne Bissett, Chief, Chemical Industries Division.

READERS' COMMENTS

Comments on the content of this report should be directed to:

E.C. Chen
Chemicals Industries Division
Industrial Programs Branch
Environmental Protection
Conservation and Protection
Environment Canada
Ottawa, Ontario
K1A 0H3

SUMMARY AND RECOMMENDATIONS

Summary: Results of the Environment Canada surveys are summarized as follows:

1) About 55% of the textile mills are located in Quebec and 40% in Ontario; the largest 10% of the mills produce more than 45% of the textile.

2) Approximately 20% of the mills use wet processing and about half of these wet textile mills belong to the woven fabric and knit fabric dyeing and finishing subcategories.

3) More than 80% of the wet processing mills discharge their effluents to a municipal system; about half of those discharging directly to a natural watercourse have wastewater treatment facilities.

4) Water usage and chemical use per unit of production as well as effluent contaminant levels have generally decreased from 1981/82 to 1985/86.

5) All mills included in the surveys and discharging to a municipal system met the BOD and TSS limits set by local municipal sewer by-law. However, some mills were found in excess of the 15 mg/L oil and grease limit.

6) Most of the mills had an effluent pH value within the range of 6 to 9.

7) Mills with secondary wastewater treatment had loadings of BOD and TSS within or close to the U.S. EPA BPT limits as well as Environment Canada's 1978 Proposed Guidelines.

8) Organic priority pollutants expected to be found in textile mill effluents, in the ppb levels, are substituted benzenes (i.e., toluene, ethylbenzene and chlorobenzenes), naphthalene, phenol, substituted phenols (i.e., chlorophenols, methylphenol and nitrophenol), chloroethylenes, chloroethanes and phthalates.

9) Metal priority pollutants expected to be found in textile mill effluents are zinc, copper, chromium, lead and nickel; the effluent concentration of these metals individually were all less than 1 mg/L, the discharge limit set by most of the local municipal sewer by-laws.

10) Calculated loadings of total phenols and chromium for effluents from all the mills surveyed are, respectively, below 0.05 kg/1000 kg of product, the limit set by EPA Textile Mill Effluent Guidelines; total phenols and chromium are used by EPA as a surrogate, respectively, for the control of organic priority pollutants and heavy metal pollutants.

11) Effluents from mills without wastewater treatment or with only primary treatment would be coloured and toxic to fish. However, mills with a well-operated biological treatment system could produce an effluent non-lethal to fish and with no apparent colour. A well-operated biological treatment system could also reduce the effluent surfactant concentration to an insignificant level.

12) Most of the textile mills did not produce sludges on a regular basis; insignificant amounts of sludges were generated occasionally from tank bottoms. However, mills with biological treatment may regularly produce some wastewater treatment sludges; these wastewater treatment sludges may contain heavy metals and chlorinated hydrocarbons.

13) Wastes other than wastewaters and sludges produced by textile mills include waste fabric, waste fibres, waste oils and latex wastes. While waste fabric and waste fibres can be properly directed to municipal landfill sites, waste oils and latex wastes must be hauled away and disposed of by a licensed contractor or incinerated on-site.

14) Most of the textile mills surveyed have some controls for particulate and fibre dust emissions. However, very few have installed control devices for solvent vapours, oil mists and odour. Although the problems of solvent vapours, oil mists and odour do not appear to be serious from the experience of plant visits, the environmental significance of these emissions is yet to be determined.

Recommendations: Based on this summary, the following recommendations are made:

1) Biological treatment is able to reduce the effluent pollutant content as well as the toxicity to an acceptable level and should be adopted as the BPT model for textile mill effluents.

2) Untreated textile mill wastewaters are toxic to fish and may be high in colour and contaminant levels; they should not be discharged directly to a watercourse or to a municipal system where there is no sewage treatment.

3) Since more than 80% of the textile mills discharge their effluents to a municipal system and about 95% of the mills are concentrated in two provinces, no further regulatory initiative at the federal level is intended at the moment for this industry sector regarding its wastewater discharges. However, provincial and municipal authorities are encouraged to adopt Environment Canada's 1978 Proposed Guidelines for BOD, TSS and pH as well as the U.S. EPA BAT limitations for phenols and total chromium for mills discharging directly to a watercourse or to a municipal system without treatment facilities.

4) Sludges, waste oils and latex wastes, although produced in small quantities and in only a few operations, can be hazardous and should be disposed of in an environmentally safe manner.

5) The environmental significance of air emissions from textile processing, particularly the emission of solvent vapours, should be determined.

6) Municipalities should carry out routine monitoring for wastes discharging to their systems and enforce their by-laws.

7) Textile mills are encouraged to engage in modernization programs which may result in a reduction in water usage and/or chemical consumption.

1 INTRODUCTION

Textiles are a major Canadian industry with direct employment of about 80 000 people and total shipments valued at $6.6 billion (1984). When combined with the clothing industry, textiles rank as the second largest employer of manufacturing workers in Canada with total employment in excess of 163 000. Indirect employment generated by textiles and clothing provides an additional 275 000 jobs across the country[1]. Products from this industry are used by all facets of the Canadian economy. In addition to their use in clothing and home finishing products, textiles are also used for industrial goods by over 150 industries.

Textile processing plants utilize a wide variety of dyes and chemicals. Many of these are not retained in the final textile product and are discarded after they have served their purpose or driven off into the atmosphere during heat treatment. The liquid effluent, air emissions, and solid wastes from a textile plant may contain any combination of chemicals and could, therefore, present an environmental problem. Besides the discharge of potentially toxic chemicals into the environment, certain local water pollution problems may also occur: organic substances in textile waste such as starches and detergents may undergo chemical or biological changes and consume dissolved oxygen from the receiving water; the presence of inorganic salts in high concentrations may render the receiving water unsuitable for most industrial and municipal uses; foaming from detergents and colours from dyes may be objectionable in drinking and recreational waters; and certain carrier chemicals used in dyeing, such as phenols, add taste and odour. In addition, oil and grease as well as highly acidic or highly alkaline wastes from these plants may be harmful to aquatic biological systems.

Recognizing the importance of this industry and its potential environmental problems, Environment Canada established a joint industry/government task force in 1974 to develop liquid effluent regulations and guidelines under the Fisheries Act for textile mills that carry out wet processes. Participants in the task force included industrial representatives from the Canadian Textiles Institute as well as provincial representatives from New Brunswick, Quebec and Ontario. The task force completed its technical work in December 1976 and the draft proposed Regulations and Guidelines were finalized in March 1978. The proposed control package would have limited the discharge of Biological Oxygen Demand (BOD) and Total Suspended Solids (TSS) as well as controlled pH levels and acute lethality to fish[2]. These proposed regulations and guidelines, however, have not been promulgated (see Appendix A).

In 1981/82, Environment Canada conducted a survey of wet textile mills consisting of a state-of-the-art industry review and a detailed survey of six selected mills. The latter included an inventory of chemicals used, a review of the wastewater treatment technology and an analysis of wastewater samples for selected parameters[3]. A toxics screening study which included evaluation/development of analytical protocol for the United States Environmental Protection Agency (U.S. EPA) organic priority pollutants in textile mill effluents and the analysis of selected effluent samples for such pollutants was also carried out during the same period.[4] In 1985/86, Environment Canada carried out an exercise to update the textile database by surveying selected mills as well as sampling/analyzing effluent samples from selected textile mills for a number of parameters including effluent fish toxicity.

This report briefly describes the industry, summarizes the information/data obtained from the surveys/studies and assesses the environmental problems associated with this industrial sector based on the available information.

2 DESCRIPTION OF THE INDUSTRY

2.1 General Description

Textiles are any product derived from the manufacture of natural fibres such as wool and cotton and/or from the manufacture of fibres synthesized and processed from petrochemicals and modified wood pulp such as polyester, nylon, rayon or acetate. The textile industry is a group of industries which manufacture man-made fibres or process natural and/or man-made fibres into yarns, fabrics and certain consumer products. The production of man-made fibres, however, is not included in this report as the nature of such plants is more closely identified with organic chemical plants. The activities of the industry referred to include:

- the production of yarns by extrusion or spinning;
- the production of fabrics by weaving, knitting and other processes;
- the dyeing and finishing of yarns and fabrics;
- the production of some clothing by knitting such as underwear, hosiery and athletic wear; and
- the production of sheets, pillow slips, towels, blankets, curtains, and carpets.

There are some 1000 textile manufacturing facilities in Canada. As mentioned earlier, the total shipments in 1984 valued at $6.6 billion; 54% of these total shipments originated from Quebec and 40% from Ontario. Textile manufacturing is also located to varying degrees in all the other provinces except Saskatchewan. About 40% of the total shipments go to the clothing manufacturing (apparel) industry; some 30% are destined for end product uses in the home such as upholstery, curtains, carpets, tablecloths, towels and bedding products; and another 30% are used for industrial goods by over 150 other industries including motor vehicle manufacturing, pulp and paper, agriculture, food processing, mining, aircraft and rubber. The "textile complex" is shown schematically in Figure 1.

The Canadian textile industry invested $1.8 billion between 1981 and 1985 and is one of the world leaders in the application of new technology[1]. Operating efficiency throughout the industry, measured by energy consumption per unit of output, has improved 21.5%[5]. However, the future of the industry does not look optimistic as imports are taking a larger and larger share of the Canadian textile and apparel markets.

The textile industry uses many different raw materials to produce a great variety of products. The classical method of categorizing the industry involves grouping the manufacturing plants according to the fibre being processed, i.e., cotton, wool or

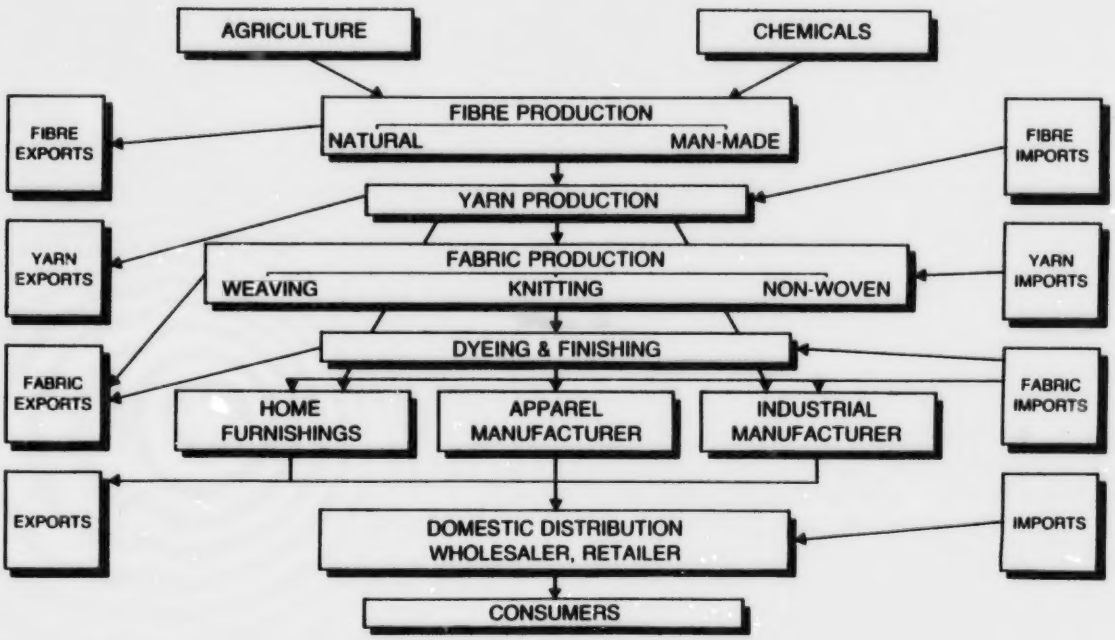

FIGURE 1 SCHEMATIC DIAGRAM OF THE TEXTILE COMPLEX
(courtesy of the Canadian Textile Institute)

synthetics. The modern approach to textile industry categorization, however, involves grouping the manufacturing plants according to their particular operation. Two broad categories can be identified: dry processing and wet processing. Dry processing includes the manufacture of yarns and unfinished fabrics ("greige" goods), while wet processing includes several subcategories according to the processes and raw materials employed in the production of the finished product. The U.S. EPA listed nine subcategories in its 1982 Textile Mill Point Source Effluent Guideline:

- wool scouring,
- wool finishing,
- woven fabric finishing,
- knit fabric finishing,
- carpet finishing,
- stock and yarn finishing,
- low water processing (water jet weaving),
- non-woven manufacturing, and
- felted fabric finishing.

In Canada, seven subcategories were identified in the 1982 Environment Canada wet textile mill survey:

- threads, yarns and fibres,
- wool finishing,
- woven fabric dyeing and finishing,
- knit fabric dyeing and finishing,
- carpet finishing,
- commission dyeing, and
- non-woven and felted fabric finishing.

Wet textile processing in Canada is limited largely to the woven fabric finishing and knit fabric finishing subcategories. Based on the 1984 Canadian Textile Manual[6] which has a list of 600 textile mills, the distribution of these seven wet processing subcategories is summarized in Table 1.

2.2 The Processes

The unit dry processes consist of carding, spinning, slashing (sizing), weaving, knitting and tufting, while the unit wet processes include desizing, scouring, wool

TABLE 1 SUMMARY OF WET PROCESSING TEXTILE MILLS IN CANADA

Subcategory	Location and Number of Plants								Total Number of Plants
	Que.	Ont.	N.B.	N.S.	P.E.I.	Man.	Alta.	B.C.	
Threads, Yarns and Fibres	17	8	1		1	1			28
Wool Finishing	3	3	1		1			2	10
Woven Fabric-Dyeing and Finishing	17	11	1	4		1			34
Knit Fabric-Dyeing and Finishing	32	22		1					55
Commission Dyeing	20	4							24
Carpet Finishing	11	6		1			1		19
Non-Woven Felted Ribbons and Webbing	5	5				1			11
TOTALS	105	59	3	6	2	3	1	2	181

carbonizing, wool fulling, cotton mercerizing, bleaching, dyeing/printing and finishing. These unit processes are briefly described in the following.

2.2.1 Dry Processing.

a) **Carding** - is the preliminary process in spun yarn manufacture. The fibres are separated, distributed, equalized and formed into a thin web and condensed into a continuous, untwisted strand of fibres called a silver. This process removes most of the impurities and a certain amount of short, broken or immature fibres. The operation is performed on a card.

b) **Spinning** - is the process of making yarns from fibres by a combined drawing out and twisting operations or by making yarns from filament tow by the combination of cutting/breaking with drafting and twisting in a single series of operations.

c) **Slashing** (sizing) - is the process of sizing warp yarns on a slasher to protect the yarns against injury during weaving. It also gives temporary added strength and abrasion resistance to the yarns to enable them to resist the strains in weaving. The entire warp is coated by immersion in the sizing material which may contain starch, gelatine, oils and other materials and dried before winding upon the beam of the loom prior to weaving.

d) **Weaving** - is the process of interlacing two yarns of similar materials so that they cross each other at right angles to produce woven fabric. The warp threads or ends run lengthwise in the fabric, and the filling threads (weft) or picks run from side to side. The three basic weaving patterns are plain, twill and satin.

e) **Knitting** - is the process of constructing fabric by interlocking series of loops of one or more yarns. Three classes of knitted fabrics are circular knit, flat knit and warp knit.

f) **Tufting** - is the process of making carpets; a wide multiple-machine needle process that sews pile yarns to a broad fabric backing.

2.2.2 Wet Processing.

a) **Desizing** - removes the sizing compounds applied to yarns to impart tensile strength. The sizing compounds are solubilized with acids or enzymes and the fabric is washed thoroughly. Acid desizing utilizes a dilute acid solution to hydrolyze the size and render it water soluble. Enzyme desizing utilizes vegetable or animal enzymes to decompose size (usually only starch size) to a water soluble form. Desizing agents are applied to the fabric and, in the case of acid desizing, fabrics are soaked for 4 to 12 hours at room temperature, and in enzyme desizing, for 4 to 8 hours at 55 to 82°C. After solubilizing the size, the fabric is rinsed clean. Two sizing agents, polyvinyl alcohol (PVA) and carboxymethyl cellulose (CMC) are water soluble and only rinsing is required to remove them.

b) **Scouring** - (or washing) removes natural and acquired impurities from fibres and fabric. Synthetic fibres require less scouring than cotton or light wool.

Scouring agents include detergents, soaps, non-ionic detergents and various assisting agents such as alkalis, anti-static agents, wetting agents, foamers/defoamers and lubricants. After scouring, the goods are thoroughly rinsed to remove excess agents.

c) **Wool Carbonizing** - removes burrs and other vegetable matter from loose wool or woven fabric goods. The process consists of acid impregnation, baking and mechanical

agitation. A solution of 4 to 7% sulphuric acid is used to degrade cellulosic impurities to hydrocellulose without damaging the wool. The excess acid is squeezed from the wool and the wool baked to oxidize the contaminants to gases and a solid carbon residue. The material then passes through pressure rollers to crush the solid residue and into a mechanical agitator to shake loose the crushed material. The acid content in the material remains high after agitation, requiring neutralization and rinsing before further processing.

d) **Wool Fulling** - gives woven woolen cloth a thick, compact feel, finish or appearance. Cloth is mechanically worked in fulling machines to make the fibres felt together, causing shrinkage, weight increase, and concealment of the woven threads of the cloth. The two common methods of fulling are acid and alkali. In acid fulling, an aqueous solution of sulphuric acid, hydrogen peroxide and small amounts of metallic catalysts is used. In alkali fulling, soap or detergent, sodium carbonate and a sequestering agent are added to provide the required lubrication. Acid fulling is usually followed by alkali fulling.

e) **Mercerizing** - is usually used in cotton processing to increase the tensile strength, luster, dye affinity and abrasion resistance of the goods. In this operation, the cotton, usually in fabric form, is impregnated with cold sodium hydroxide solution of 15 to 30% by volume. The solution causes the cotton fibres (cellulose) to swell. After the desired contact period, the alkali is thoroughly washed out, sometimes with the aid of a dilute acid bath. It has been normal practice to recover the caustic solution for concentration and re-use in scouring or mercerization.

f) **Bleaching** - is a common process used to whiten cotton, wool and some synthetic fibres by removing the natural colouring. It is usually performed after scouring and prior to dyeing or printing. Bleaching chemicals include hydrogen peroxide or sodium perborate as well as optical brighteners. Batch bleaching is done in kiers (continuous processes use J-boxes) where fabric is stacked for a given period to allow the chemical to work before goods are withdrawn from the bottom of the box. Bleaching is followed by thorough rinsing.

g) **Dyeing** - can be performed in the stock, yarn or fabric state, and single or multiple fibre types can be dyed. Multiple fibre types may require multiple or sequential steps.

Stock dyeing is performed before the fibre is converted to the yarn state. The process consists of placing the stock in a vat or pressure kettle, applying a sufficient amount of dye solution, providing optimum environmental conditions, allowing time for the reaction, and rinsing. The stock is then processed into yarn.

Yarn dyeing is performed on yarns used for woven goods, knit goods and carpets. Usual methods include skein, package and space dyeing. Skein dyeing is performed by placing turns of yarn on a frame and placing the frame in a dye bath under the required dyeing conditions. Package dyeing is the most common yarn dyeing process and is effected by placing yarn wound onto perforated tubes on a frame, placing the frame into a pressure vessel, circulating dye liquor in and out of the tubes under the required conditions, and then rinsing. Space dyeing is a specialty yarn dyeing process. Dye liquor is applied to yarns at a repeat or random interval by a roller type dye pad. The dyed yarn then enters a hot water steam box for development and fixation of the colour and is rinsed.

Fabric dyeing is the most common method in use today because it is a continuous or semi-continuous process. Methods employed include beck (winch), jet, jig, and continuous range. Beck dyeing is accomplished with the fabric in rope form in either atmospheric or pressure vessels. The fabric is connected end-to-end and rotated over a large drum

through the dye liquor. The length of the fabric is such that the fabric lies in a heap at the bottom of the vessel for a short time. As with all dyeing methods the proper conditions of time and chemicals must be provided.

Jet dyeing is also accomplished with the fabric in the rope form. Jet machines are similar to pressure becks except that each loop of cloth passes through a venturi tube. A pump circulates the dye liquor through the tubes and the suction at the venturi causes the fabric to rotate. Jet machines have improved on certain deficiencies of beck dyeing by allowing lower liquor-to-cloth ratios, reducing occurrence of tangling, providing a more uniform temperature, and reducing elongation of fabric due to tension. Jet dyeing is especially suitable for synthetic fibres.

Jig dyeing is performed with the fabric in the open width; both atmospheric and pressure equipment are available. Fabric is wound onto rollers that pass the fabric through a shallow trough containing the dye liquor. The rollers rotate in clockwise and counterclockwise directions alternately and guide rolls ensure complete immersion of the cloth. Only a few metres of cloth are immersed at a time and it is possible to work with a low liquor-to-cloth ratio.

Continuous dyeing is also performed with the fabric in the open width on what are termed ranges. The ranges consist of a number of dip troughs in which the fabric is dyed, rinse boxes to remove excess dye liquor, and drying ovens.

A modification of the continuous dyeing is the use of a kettle where open width fabric is wound onto a perforated drum and dye solution circulated in a manner similar to package yarn dyeing. This is unlike the other fabric dyeing processes described, where the fabric is circulated through the dye solution.

Thermosol dyeing is a continuous process normally used for dyeing polyester and polyester/cotton blends. Dye is applied to the fabric in the pigment form and dried, causing a film pigment to adhere to the fabric. The fabric is then heated to 180 to 200°C (near the melting point of polyester) causing the fabric to swell or melt. The dye sublimates and penetrates the fabric.

h) **Printing** - is similar to dyeing although print colour is applied to specific areas of the cloth to achieve a planned design instead of colouring the whole cloth. Dyes and dyeing assists are similar to fabric dyeing; however, the colour application techniques are quite different. Textiles are usually wet-printed by roller machines or by the screen method.

Roller printing is accomplished by applying print paste to an etched or engraved roller, and transferring the design to the fabric by contact with the rollers. After printing, the pattern is fixed by steaming, aging or other treatment.

Screen printing differs from roller printing in that the print paste is transferred to the fabric through openings in specially designed screens. The process can be manual, semi-automatic or completely automatic. Automatic screen printing can be either flat-bed or rotary, while manual and semi-automatic are flat-bed processes only.

Screens are made by manually or photographically transferring the desired design onto the screen material, usually a synthetic. The area outside the design is opaqued so that print paste is retained. The screens are securely stretched over a frame for correct positioning. A separate screen is required for each colour in the design.

In manual screen printing, the fabric is placed on a long table, the screen frames correctly positioned for the pattern, and the selected print paste forced through the screen mesh

onto the fabric by squeegee. The fabric is then dried and given other finishing treatments. In the semi-automatic process the fabric travels and the screens remain in place. Handling of screens and application of print paste are performed manually.

Automatic flatbed screen printing takes place on a machine that electronically performs and controls each step. The process is continuous in that the fabric moves along a table, the screens are positioned, print paste is applied and squeegeed through the screen onto the fabric. The fabric moves forward one frame between each screen, and when all colour has been applied, moves into a steaming and/or drying box.

In rotary screen printing, the colour is applied to the fabric through lightweight metal foil screens that resemble the cylinder rollers of the roller printing process. The fabric moves continuously under the cylinder screens and print paste is forced, under pressure, from the inside of the screens through and onto the fabric. A separate screen is required for each colour in the design.

i) **Finishing** - operations are included as wet processes because the majority of treatments are applied in the liquid state. Wet finishing involves the application of a wide range of chemicals to extend the functions of a fabric through suitable properties. Finishes can be applied to make a fabric wrinkle-resistant, crease-retentive, water repellant, flame-resistant, mothproof, mildew resistant, bacteriostatic and stain resistant. Application is usually by means of rollers (or calendars) that transport the finish from a trough to the fabric surface. The fabric is then dried to cure the finish onto the fabric.

Synthetic resins are most often used to achieve wrinkle resistance and crease retention (permanent press). The resins are adhesive and are permanently cross-linked (polymerized) with the fibres by curing with heat and a catalyst.

Silicones and other synthetic materials are used to provide water repellancy. The silicones successfully repel oily fluids as well.

Flame resistant finishes are applied to cellulosic fabrics (cotton) to prevent them from supporting combustion. Phosphorus in the form of tetrakis(hydroxymethyl) phosphonium chloride (THPC) is the essential ingredient of many flame retardant formulations.

Mothproofing finishes containing silicofluoride and chromium fluoride are typically applied to wool and other animal hair fibres to make them unfit as food for moth larva.

The growth of mildew, mold, rot and fungus is inhibited by application of toxic compounds usually containing chlorinated phenols, metallic salts or zinc, copper or mercury. Selected hygienic additives can also be used to inhibit the growth of bacteria.

Soil release finishes usually contain organosilicone compounds, fluoro compounds or oxazoline derivatives. These compounds allow stains to be removed by ordinary washing.

2.3 Dyes and Chemicals Used

Dyes used by the textile industry are classified according to application:

a) **Acid Dyes** - are sodium salts, usually of sulphonic acids or carboxylic acids and are the main class of dyes used in wool dyeing. Most will not exhaust onto cotton fibres but some do because of a chemical composition similar to direct dyes.

b) **Direct Dyes** - resemble acid dyes in that they are sodium salts of sulphonic acids and are almost invariably azo compounds. They are used primarily for the dyeing of cellulosic fibres (e.g., cotton).

c) **Basic Dyes** - are usually hydrochlorides of salts or organic bases. The pigment is found in the cation and the dyes are often referred to as cationic dyes. They are mainly used on acrylic fibres since cellulosic fibres (cotton) have no affinity for basic dyes.

d) **Disperse Dyes** - are suspensions of finely divided organic compounds with very slight aqueous solubility. These dyes were developed to dye hydrophobic fibres such as cellulose acetate and the synthetic fibres.

e) **Mordant Dyes** - include natural and synthetic dyes, the latter usually obtained from anthracene. They have no natural affinity for textile fibres but can be applied if the fibre has been mordanted with a metallic oxide. The most commonly used mordant is chrome and these dyes can be referred to as chrome dyes. The dyes are most commonly applied in a boiling acid dyebath and when dye uptake by the fibre is complete, a solution of dichromate is added.

f) **Pre-Metallized Dyes** - are a variation of mordant dyes with the metallic oxide, again usually chrome, already included in the formulation. This eliminates the need for addition of the dichromate as a second step in the process.

g) **Reactive Dyes** - are generally referred to as fibre reactive dyes. They react chemically with functional groups on the fibre and because of this feature possess good light fastness properties. They can be applied to most fibre types (e.g., cotton, nylon, linen, wool and silk) and can be applied by most dyeing methods. A common method, utilizing a continuous system, is to impregnate the fibre with the dye and a resin followed by baking to polymerize and insolubilize the resin to fix the dye.

h) **Sulphur Dyes** - are complex organic compounds that contain sulphur linkages within the molecules. They are usually insoluble in water but will decompose into soluble components in the presence of a reducing agent such as sodium sulphide. The soluble components have an affinity for cellulose (cotton) and once on the fibre are oxidized back to the original insoluble form. These dyes have excellent resistance to washing but poor resistance to sunlight, and are not very bright.

i) **Vat Dyes** - are made from indigo, anthraquinone and carbazol and are used on cotton, linen, rayon, wool, silk and sometimes nylon. They are insoluble in water, but when treated with reducing agents are converted into soluble compounds in the presence of alkali. The soluble compounds have an affinity for cellulose and reoxidize to the insoluble coloured pigment within the fibre when exposed to air.

Auxiliaries required for satisfactory dyeing are listed in Table 2. Other chemicals used in different textile processes are listed in Table 3.

2.4 Waste Generation and Characteristics

2.4.1 Wastewaters. Textile wastewaters are variable in quantity and composition depending on the processes and raw materials used. The wastewaters are usually characterized by a high organic loading as well as a high solid content; the main components include natural impurities in fibres and process chemicals. The wastewaters are generated from various wet processes. However, dry processing may also produce small volume of wastewaters, e.g., at greige mills wastewaters containing residual size

TABLE 2 AUXILIARIES REQUIRED FOR SATISFACTORY DYEING

Chemical Auxiliary	Type of Dye								
	Acid	Direct	Basic	Disperse	Mordant	Pre-metallized	Reactive	Sulphur	Vat
Acetic Acid	X		X	X	X	X		X (or alternative acids)	X
Ammonium Acetate	X								
Ammonium Phosphate	X								
Ammonium Sulphate	X				X	X			
Aromatic Amines		X							
Buffer							X		
Dispersing Agents				X					X
Formic Acid	X		X		X	X			
Gelatin									X
Hydrochloric Acid		X							
Hydrogen Peroxide								X	X
Levelling or Retarder Agents	X		X						
Organic Carriers (e.g., orthophenyl-phenol, chloro-benzene, diethyl phthalate, methyl naphthalene, toluene)				X					
Oxalic Acid			X						
Penetrating Agents					X	X			
Potassium Dichromate					X	X			
Sequestering Agents		X							
Sodium Acetate			X						
Sodium Carbonate		X					X	X	
Sodium Chloride		X					X	X	
Sodium Dichromate					X	X		X	
Sodium Hydrosulphite									X
Sodium Hydroxide							X		X
Sodium Nitrate		X							
Sodium Sulphate (Glauber's salt)	X		X		X	X			
Sodium Sulphide								X	
Soluble Oil									X
Sulphuric Acid	X				X	X			
Urea							X		
Wetting Agent		X							

TABLE 3 OTHER CHEMICALS USED IN DIFFERENT TEXTILE PROCESSES

Textile Process	Chemicals	
	Major	Minor
Printing	- dyestuffs - gums - solvents - alcohols	- ammonium - sodium alginate - soda ash - hypochlorite - soaps and detergents
Bleaching	- peroxide - hydrosulphite - hypochlorite - sodium phosphates - salt	- sodium silicate - caustic soda - stabilizers - soda ash
Slashing	- cornstarch - polyvinyl acid - carboxymethyl cellulose - soaps	
Spinning	- wool oil	
Carpet Finishing	- latex - calcium carbonate - Minex - aluminum hydrate - thickeners - styrene butadiene rubber	
Scouring	- detergents - soda ash - softeners - caustic - sodium phosphate - surfactants	
Fibre Preparation	- oleic acid	
Special Finishing	- softening agents (oils, waxes, soaps) - stiffeners (PVA, ethyl cellulose) - permanent press (resins) - shrink-proofing (cross-linking resins) - oil repellents (perfluorofatty acids and acrylates) - water repellents (silicone resins) - antistatic finishes - fire retardants (triaziridylphosphine azide) - bactericides (trichlorophenol) - moth proofer (dieldrin)	

compounds are generated from washing of size boxes and at adhesive-related operations, such as carpet backing or non-woven mills, wastewaters containing bonding chemicals, mainly latex, may be generated from washing of equipment.

Unit wet processing operations as described previously include scouring, desizing, fulling, carbonizing, mercerizing, bleaching, dyeing/printing and finishing; wastewater generation and characteristics from these operations are briefly described in the following:

a) **Scouring** - uses water and selected chemical reagents to wash impurities from fibres and/or fabrics. The water, after use in washing, becomes wastewater. The water use per unit weight of product as well as typical characteristics of wastewaters from scouring different types of fibres are given in Table 4.

TABLE 4 TYPICAL CHARACTERISTICS OF SCOURING WASTEWATERS FOR SELECTED FIBRES

	Wastewater Parameter			
Fibre	BOD (mg/L)	TSS (mg/L)	pH (units)	Water Use (L per 1000 kg of product)
Wool*	1 000 to 10 000	1 000 to 30 000	9 to 11	46 000 to 100 000
Cotton	100 to 2 900	2 200 to 17 400	10 to 13	2 500 to 43 000
Rayon	2 800	3 300	8 to 9	17 000 to 33 500
Acetate	2 000	2 000	9 to 10	25 000 to 83 500
Nylon	1 300	1 800	10 to 11	50 000 to 66 750
Acrylic	2 100	1 800	9 to 10	50 000 to 66 750
Polyester	500 to 800	600 to 1 400	8 to 10	25 000 to 42 000

* this is for heavy scouring of raw wool fibres which is not performed in Canada

b) **Carbonizing** - uses sulphuric acid to remove burrs and vegetable matter from wool fibres; the fibres require neutralization and rinsing before further processing. Solutions used for neutralization and rising water are sources of wastewaters. The water use is 17 000 to 135 000 L per 1000 kg of product. Typical wastewater characteristics are: BOD 15 to 100 mg/L; total solids 100 to 10 000 mg/L; and pH 2 to 9.

c) **Fulling** - uses acid, alkali and selected chemicals to give woolen cloth a thick and compact feel and must be followed by an extensive washing to remove the chemicals. A typical fulling uses 125 000 to 835 000 L of washwaters per 1000 kg of product. The washwaters (i.e., wastewaters) usually have the following characteristics: BOD 200 to 10 000 mg/L; total solids 4000 to 10 000 mg/L; and pH 7 to 12.

d) **Desizing** - uses water to rinse out water soluble sizing agents from fabrics. If the sizing compounds are insoluble in water, acids or enzymes are used first to make them water soluble. Water use and wastewater characteristics of the operation depend on the size and desizing method used; typical values are: water use 2500 to 21 000 L per 1000 kg of product; BOD 200 to 5200 mg/L; total solids 400 to 4000 mg/L; and pH 6 to 8.

e) **Mercerizing** - cotton fibres are impregnated with cold caustic solution to increase tensile strength, luster, dye affinity and abrasion resistance; followed by a thorough washing to remove caustic from the fibres. Water use and wastewater characteristics depend on the concentration of caustic solution used and the caustic recovery practice. Typical values are: water use 17 000 to 320 000 L per 1 000 kg of product; BOD 50 to 800 mg/L; total solids 300 to 18 000 mg/L; and pH 5 to 14.

f) **Bleaching** - uses chemical agents such as hydrogen peroxide to whiten wool, cotton and some synthetics. It is followed by thorough rinsing which is the source of wastewaters. Water use and typical wastewater characteristics are given in Table 5.

TABLE 5 TYPICAL CHARACTERISTICS OF BLEACHING EFFLUENTS FOR SELECTED FIBRES

	Wastewater Parameter			
Fibre	BOD (mg/L)	TSS (mg/L)	pH (units)	Water Use (L per 1000 kg of product)
Cotton	100 to 1 700	800 to 15 000	8 to 12	2 500 to 125 000
Wool	400	900	6	2 500 to 25 000
Acetate	700	800 to 1 000	7 to 9	33 500 to 50 000

g) **Dyeing/Printing** - dyeing involves contacting fibres, yarns or fabrics with a dye bath and rinsing the goods with water. The used dye bath and rinsing water are the wastewater sources. Printing involves transferring colour printing pastes from a roller or screen to fabrics/cloths; the sources of wastewater are printing paste formulation, equipment washings and washing of printed goods. Water use and wastewater characteristics depend on fibre, dye type, operating condition and equipment used. Table 6 presents some typical values for the dyeing and printing of various fibres.

h) **Finishing** - finishing involves the application of chemicals, usually in the liquid state, to extend the function of a fabric through suitable properties. Finishing does not generate a continuous wastewater stream, but may result in spills, clean-out effluents and chemical dumping. Examples of finishing wastewater characteristics are[7]:

	BOD	TSS	pH
cotton	20 to 500 mg/L	40 to 1700 mg/L	6 to 8
synthetic fibres	2 to 80 kg per 1000 kg of product	3 to 100 kg per 1000 kg of product	

TABLE 6 TYPICAL CHARACTERISTICS OF WASTEWATERS FROM DYEING AND PRINTING OF VARIOUS FIBRES

Fibre	Wastewater Parameter			
	BOD (mg/L)	TSS (mg/L)	pH (units)	Water Use (L per 1000 kg of product)
Cotton	60 to 10 000	10 to 800	1 to 12	8 500 to 300 000
Wool	400 to 3 000	2 000 to 10 000	5 to 8	16 700 to 25 000
Rayon	2 800	3 500	8 to 9	16 700 to 33 500
Acetate	2 000	2 000	9 to 10	33 500 to 50 000
Nylon	400	600	8 to 9	16 700 to 33 500
Acrylic	200 to 2 000	800 to 2 000	1 to 4	16 700 to 33 500
Polyester	500 to 27 000	300 to 3 000	6 to 9	16 700 to 33 500

2.4.2 Air Emissions. Possible emissions from textile processing include:

a) **Oil mists** produced when textile materials containing oils, plasticizers and other materials that can volatilize or be thermally degraded into volatile substances are subjected to heat. Processes which are the sources of oil mists include tentering, calendaring, heat setting, drying and curing.

b) **Acid mists** produced during the carbonizing of wool.

c) **Solvent vapours** released during and after all solvent processing operations such as dry cleaning.

d) **Dust and lint** produced by the processing of natural fibres and synthetic staple prior to and during spinning as well as by napping and carpet shearing, while most of other textile processes produce lint.

2.4.3 Solid Wastes. Textile processing does not produce large quantities of solid wastes. The solid wastes that are produced include miscellaneous garbage, fabric cuttings, floor sweepings, screened or settled fibres, wastewater treatment sludges and latex wastes. The wastewater treatment sludges may contain a significant amount of heavy metals and may be hazardous; latex wastes could be toxic.

2.5 Waste Treatment Technologies

2.5.1 Wastewater Treatment. Textile wastewaters are variable both in strength and flow because of the various processing systems used. However, they are generally coloured, high in BOD (organic loading) and TSS as well as highly alkaline and hot. Treatment of wastewaters may be drawn from the following unit operations:

Primary Treatment	-	Physical	- equalization - screening - clarification/sedimentation
	-	Chemical	- neutralization - coagulation/precipitation
Secondary Treatment	-	Biological	- activated sludge - extended aeration - lagoons - facultative - aerobic
	-	Physical/Chemical	- powdered activated carbon addition to biological processes
Tertiary Treatment	-	Physical	- secondary clarification - mixed media filtration - ultrafiltration - granular activated carbon (GAC) - powdered activated carbon (PAC)
	-	Chemical	- coagulation/precipitation - ozonation - chlorination

Selected unit operations are discussed in the following sections with reference to removals of compounds typically found in textile processing effluents.

Primary Treatment. Primary treatment removes coarse, suspended and colloidal solids. Treatment processes are screening, equalization, neutralization and clarification.

Screening removes relatively coarse, floating and suspended solids by straining through racks or screens. Screening prevents clogging of pipes and losses of efficiency in downstream treatment processes. Screens are classified as coarse screens (openings 6 mm or greater) and fine screens (openings less than 6 mm). Coarse screens remove rags, sticks, and coarse material. Fine screens remove floc, string, short fibres, or other small solids. The types of screens available include:

- a hand cleaned bar rack,
- a mechanically cleaned bar rack,
- a vibrating screen,
- a hydrasieve, and
- a rotating drum screen.

Equalization provides uniform conditions of flow and/or concentration upstream of physical, chemical or biological treatment systems. Wide flow fluctuations can be equalized using pumps, siphons, valves or storage tanks.

Equalization can be used to level the organic loadings to downstream treatment processes. Particular streams such as the desize and scour effluent of cotton mills, the post fulling scour and wash effluent of woolen mills, and the knitting oil scour effluent of polyester knit mills can be segregated from the main flow and stored in smaller equalization basins. These flows, generally 1 to 3% of total mill flow, are segregated to provide equalization for 50 to 90% of the total BOD loading of the mill. Lagoons having detention times greater than 24 hours are common equalization facilities. Equalization basins provide a heat sink and allow cooling of discharge waters. Typical lagoons may be constructed from earth, concrete or steel. Earth construction is usually the most cost effective.

Neutralization. Textile wastes are usually within a pH range of 5 to 12 due to the acidic nature of dye wastes and alkaline nature of washing and scouring wastes.

Acidic wastes are neutralized with lime, sodium carbonate or sodium hydroxide. Lime is usually the cheaper chemical but is difficult to handle and produces large quantities of sludge for further disposal. Alkaline wastes may be neutralized using strong acids or boiler flue gas containing carbon dioxide (CO_2) and sulphur dioxide (SO_2).

Chemical Coagulation and Precipitation can be performed either as a primary or as a tertiary treatment step. Chemicals are added to the wastewater stream to remove colloidal, suspended organic or inorganic (especially phosphorus) material. Chemicals of choice are usually aluminum sulphate (alum), lime, and iron salts (ferric or ferrous sulphate and chloride).

Removal efficiencies for wastewater parameters by addition of alum, lime and ferric sulphate have been developed by a number of researchers and are summarized in Table 7(8 to 10). Disperse dyes can be removed from raw wastewaters with reasonable effectiveness by coagulation. However, reactive dyes are not amenable to chemical coagulation. The removal efficiencies presented in Table 7 may be optimistic if most of the dyes used are reactive.

Clarification or sedimentation effects solids removal through gravity settling. Sedimentation can be utilized in process treatment systems for equalization, organics removal, inorganics removal, and chemical coagulation. Retention times are in the order

TABLE 7 REMOVAL EFFICIENCIES FOR STANDARD PARAMETERS WITH SELECTED CHEMICAL COAGULANTS

Pollutant	% Removal		
	Alum	Lime	Ferric Sulphate
BOD	50 to 70	-	-
COD*	28 to 70	29 to 80	30 to 58
Solids			
- total	5	-	-
- volatile	50	-	-
- suspended	80 to 98	-	-
Colour	72 to 95	68 to 91	75 to 90
Alkalinity	0 to 20	-	-

* Chemical Oxygen Demand

of three hours with scum and settleable solids removal accomplished mechanically. Removal efficiencies of 5 to 15% for BOD and 15 to 60% for suspended solids have been reported(11).

Secondary Treatment. Secondary treatment provides major reductions in the amounts of dissolved organic matter and suspended solids in wastewaters. Selected secondary treatment processes include lagoons, activated sludge, activated carbon addition, and chemical coagulation.

Lagoons are considered low-rate secondary treatment processes and are classified into the following four types: aerated lagoons, facultative ponds, anaerobic ponds, and polishing ponds.

Aerated lagoons have been used by the textile industry to provide cost-effective secondary treatment. Retention times vary from 2 to 10 days. Lagoon depths range from 2.5 to 4.5 m. Oxygen is introduced into the lagoon by fixed mechanical turbine, floating propeller-type low speed aerators or a diffused air system. Biological solids removal is usually effected in a quiescent section of the lagoon or by secondary clarification.

BOD and suspended solids reductions vary widely from 50 to 90% depending on detention time, temperature and degree of mixing. Lagoon design is based on:

- BOD removal rate,
- oxygen requirements,
- temperature effects, and
- energy required for mixing.

Some reported removal efficiencies for aerated lagoons with standard pollutant parameters are BOD: 0 to 91% removal and COD: 3 to 23% removal. (12, 13)

Activated Sludge-Extended Aeration. The extended aeration modification of the activated sludge process is most commonly used in the textile industry for secondary treatment of wastewaters. This process allows longer contact times between the activated sludge mixture and raw waste in the aeration chamber. For textile wastewaters, aeration periods of 36, 48, 60, 72, 96 or over 120 hours may be required. Despite high organic removals from the wastewaters, less biological sludge is produced than in conventional activated sludge units.

Oxygen is introduced into the aeration basin by mechanical aerators or diffused air systems. BOD removals of greater than 90% have been achieved. The process is more resistant to shock loads than conventional activated sludge systems. Secondary sedimentation for biological solids removal and recycle is required. Reported removal efficiencies of standard parameters are given in Table 8(10,12,13).

Adsorption of various dye stuffs by activated sludge has been reported (Table 9) (14). This appears to be a major mechanism for colour removal in biological processes.

Activated carbon (powder) has improved BOD, COD and colour removal when added to the aerobic reactor of a biological treatment system. Foaming in the reactor can also be reduced.

Carbon is fed daily to the reactor to maintain the activated carbon level at about 25% of the reactor mixed liquor suspended solids (MLSS) with a relatively low level of sludge wasting. Carbon content is closely controlled to prevent the buildup of inert material which could reduce the biologically viable component of the MLSS. Carbon carryover from the reactor is not normally a problem; however, chemical treatment may be required. Spent carbon can be concentrated by gravity thickening and vacuum filtration or by dewatering. Regeneration can be practiced if large amounts of carbon are used; otherwise spent carbon is disposed of.

A summary of removal efficiencies for various parameters by selected secondary treatment unit processes is presented in Table 10(3). Extended aeration and activated sludge treatment processes provide significantly higher reductions of COD and TSS. While this table may be used as a guide for removal efficiencies, actual efficiencies will depend on the wastewater characteristics.

In its 1979 development document, the U.S. EPA summarized removal efficiencies for selected parameters for the various categories of textile wet processing

TABLE 8 REMOVAL EFFICIENCIES FOR STANDARD POLLUTANT PARAMETERS BY EXTENDED AERATION ACTIVATED SLUDGE

Pollutant	% Removal
BOD	70 to 95
COD	30 to 90
Solids	
-total	5 to 80
-volatile	10 to 50
-suspended	30 to 90
Colour	10 to 80
Alkalinity	10 to 20

TABLE 9 ADSORPTION OF DYES BY ACTIVATED SLUDGE

Type of Dye	% Adsorption
Acid	0 to 100
Reactive	0 to 43
Direct	34 to 99
Disperse	13 to 95
Basic	64 to 100

TABLE 10 REMOVAL EFFICIENCIES FOR SELECTED PARAMETERS BY SECONDARY TREATMENT UNIT PROCESSES IN TEXTILE WET PROCESSING

	% Removal Efficiencies			
Unit Treatment	BOD	COD	TSS	Colour
Aerated Lagoons	0 to 90	3 to 25	-	-
Extended Aeration	70 to 98	30 to 90	5 to 80	10 to 80
Activated Carbon in Addition to Activated Sludge	5 to 75	20 to 70	-	50 to 80

mills. These mills were considered to practice best practicable technology (BPT) (see Table 11) treatment consisting of:

- extended aeration activated sludge (minimum 24- h retention time);
- secondary sedimentation; and
- biological sludge return to the aeration basin.

TABLE 11 PERCENT REMOVAL EFFICIENCIES FOR SELECTED PARAMETERS IN TEXTILE MILLS PRACTISING BEST PRACTICABLE TECHNOLOGY (BPT)[12]

Subcategory	% Removal			
	BOD	COD	TSS	Colour
Wool Scouring	96	71	79	14
Wool Finishing	71	12	-	33
Woven Fabric Finishing				
- simple processing	94	73	33	58
- complex processing	93	77	55	-
- complex processing plus designing	94	80	67	94
Knit Fabric Finishing				
- simple processing	93	69	30	53
- complex processing	93	65	8	90
- hosiery products	78	58	-	-
Carpet Finishing	92	76	14	37
Nonwoven Manufacturing	-	-	-	-
Felted Fabric Processing	-	-	-	-

Tertiary Treatment. Tertiary treatment can be used to remove residual solids and organic matter remaining in effluents after secondary treatment. Tertiary treatment unit processes include multi-media filtration, activated carbon treatment, chemical coagulation and precipitation, reverse osmosis, and ozonation.

Filtration is the most common form of advanced wastewater treatment practiced for removal of residual suspended solids. Multi-media filtration using coarse-to-fine filtration is most commonly practiced. Filtration units may function by either gravity or pressure.

Chemical Coagulation and Precipitation. As a tertiary process, chemical coagulation and precipitation is used in the textile industry for removal of colour and residual dissolved organic material from secondary effluent. Coagulants such as alum, iron salts and lime have proven successful for colour removal from dispersed, vat and sulphur dyes. At dosage rates of 300 to 600 mg/L of any of the coagulant chemicals, 75 to 90% colour removal has been observed. Sludge handling equipment is an integral part of the process and each chemical produces unique quantities and types of chemical sludge requiring detailed engineering of the entire system. Colour removal rates of 50 to 94% and total organic carbon (TOC) removal rates of 14 to 64% are common using alum addition.

Colour and BOD removal efficiencies in raw wastewater were compared[13] using a number of chemicals (Table 12). The use of chemical coagulation and precipitation in lieu of activated sludge treatment for these wastes results in colour removal efficiencies similar to activated sludge treatment.

Activated carbon is effective in reducing soluble organic levels and colour in textile wastewaters. The mechanism of removal is adsorption of the molecule onto the surface of the carbon. A hierarchy of adsorption exists which depends on molecular structure, molecular weight and polarity. Activated carbon is generally effective in removing colour from reactive, acid, azoic and metal complex dyeing wastewaters. Removal efficiencies for selected parameters using carbon adsorption are presented in Table 13[11].

Granular activated carbon has been used in columns set up in series and parallel, and in moving bed operations[15]. In series operation, columns are piped to allow removal of an exhausted carbon bed with no downtime in the overall process. Parallel columns receive a split feed and the effluents are blended as a final effluent. With parallel columns, a minimum of two complete systems is required to allow regeneration or refilling of spent columns and avoid downtime. In moving bed systems, the carbon bed moves countercurrent to the flow of wastewater. Spent carbon is removed from the bottom of the column and fresh carbon fed from the top. Effluent is injected into the bottom of the column and removed from the top. In this manner, dilute liquid is treated for organic or colour removal by fresh carbon.

Parallel systems can be used when large volumes of relatively low levels of impurity removal and/or short residence times are required, but, in general, moving bed and series systems are more commonly used for carbon adsorption.

TABLE 12 TREATMENT OF TEXTILE DYE WASTES BY CHEMICAL COAGULATION

Waste	Coagulant Chemicals	% Removal	
		BOD	Colour
A	Ferrous Sulphate ($FeSO_4$) Lime*	41.5	91.0
A	Alum Sulphuric Acid (H_2SO_4)	42.7	97.5
A	Calcium Chloride ($CaCl_2$)	42.5	85
B	Ferrous Sulphate ($FeSO_4$)	42.5	80
B	Ferrous Sulphate ($FeSO_4$) Lime*	52.5	80
B	Alum Sulphuric Acid (H_2SO_4)	56.9	90
B	Calcium Chloride ($CaCl_2$)	49.0	84

Waste A - wastewater from sulphur and indigo dye mill
Note: 14 days storage in lagoon effected no observable reduction in colour

Waste B - wastewater from vat, sulphur, and indigo dyeing and finishing mill

* high calcium hydrate $Ca(OH)_2$ representative value

TABLE 13 REMOVAL EFFICIENCIES FOR SELECTED PARAMETERS USING CARBON ADSORPTION

Parameter	% Removal
BOD	60 to 95
COD	60 to 95
Solids	
- total	10 to 30
- volatile	50 to 80
- suspended	60 to 90
Colour	80 to 98
Alkalinity	5

Moving bed and series systems are used to maximize the use of activated carbon as textile wastes require long a contact time and high carbon usage to maintain effluent quality.

Granular activated carbon is most often employed in the columns used for tertiary treatment as powdered activated carbon requires an extremely efficient solids removal pretreatment process to avoid solids plugging of the columns.

Reverse osmosis (hyperfiltration) is a membrane filtration process that effects removal of dissolved organic and inorganic impurities. A pressure high enough to overcome osmotic pressure (usually on the order of 2500 to 7000 kPa) is applied to a solution on one side of a semipermeable membrane. The membrane allows solvent molecules (usually water) to pass but retains the dissolved solute.

Membranes are usually made of cellulose acetate or proprietary polymeric formulations. Each membrane operates most efficiently at specified ranges of pH, temperature and extensive laboratory and pilot-scale work is required before full-scale design.

Removal efficiencies for selected parameters using reverse osmosis systems are presented in Table 14[11].

Ozonation. Ozone has been used primarily as a disinfectant for potable water supplies, but its high oxidizing power makes it attractive for use in degrading toxic compounds remaining in wastewaters after secondary treatment. A major disadvantage of the use of ozone is its cost since, because of its instability, ozone must be generated on-site.

The effectiveness of ozone treatment for colour and organic removal depends on the pH of the waste stream[16,17]. Colour reduction on a carpet mill waste was reported as high as 80% using an ozone dose of 15 mg/L[17]. Organic removal efficiencies on textile wastes as measured by COD ranged from 0 to 50% using an ozone dose of 1000 mg/L but colour removals of 80% were noted[18].

The U.S. EPA developed a summary of the treatment efficiencies of selected tertiary treatment processes applied to secondary effluents[12]. A summary of the information is presented in Table 15.

Toxicity Removal. Numerous compounds used at textile mills have been identified as being toxic to aquatic life. Studies on removal efficiencies for these specific compounds would be prohibitively expensive and time consuming. The U.S. EPA examined the levels of removal of toxicity to algae and fish and specific toxic pollutants achieved

TABLE 14 REMOVAL EFFICIENCIES FOR SELECTED PARAMETERS USING REVERSE OSMOSIS TREATMENT

Parameter	% Removal
BOD	80 to 98
COD	80 to 98
Solids	
- total	70 to 98
- volatile	75 to 98
- suspended	95 to 100
Colour	95 to 100
Alkalinity	80 to 95

TABLE 15 REMOVAL EFFICIENCIES FOR SELECTED PARAMETERS BY TERTIARY TREATMENT UNIT PROCESSES IN TEXTILE WET PROCESSING

	Removal Efficiencies (%)				
Unit Treatment	BOD	COD	TSS	TOC	Colour
Chemical Coagulation	25 to 95	10 to 85	0 to 98	5 to 85	0 to 10
Multi-media Filtration	0 to 30	5 to 25	60 to 70	5 to 15	-
Multi-media Filtration and Precoagulation	0 to 70	0 to 25	0 to 90	0 to 30	0 to 65
Ozonation	-	15 to 90	30 to 35	5 to 35	70 to 80
Activated Carbon Treatment	30 to 99	5 to 97	0 to 99	35 to 97	0 to 75

by selected tertiary systems treating secondary effluents from textile plants[12]. Eight treatment schemes involving one or more unit processes were examined, including:

- sedimentation;
- coagulant addition followed by flocculation/sedimentation;
- multi-media filtration;
- coagulant addition followed by multi-media filtration;
- coagulant addition followed by flocculation/sedimentation followed by multi-media filtration;

- multi-media filtration followed by granular activated carbon;
- multi-media filtration followed by ozonation; and
- coagulant addition with flocculation/sedimentation followed by multi-media filtration and granular activated carbon.

The demonstrated capabilities of the eight treatment systems to remove toxic pollutants and toxicity, as measured by bioassay tests, were:

- Removal of Toxic Organic Compounds - insufficient data on which to base conclusions.
- Removal of Toxic Metals - best removal ability: multi-media filtration; flocculation/sedimentation followed by multi-media filtration; multi-media filtration followed by activated carbon; intermediate removal ability: sedimentation; flocculation/sedimentation; flocculation/sedimentation followed by multi-media filtration and activated carbon; and least removal ability: multi-media filtration with precoagulation; multi-media filtration followed by ozonation.
- Removal of Acute Toxicity - best removal ability: multi-media filtration; multi-media filtration followed by activated carbon; intermediate removal ability: sedimentation; flocculation/sedimentation followed by multi-media filtration; multi-media filtration followed by ozonation; flocculation/sedimentation followed by multi-media filtration and activated carbon; and least removal ability: flocculation/sedimentation; multi-media filtration with precoagulation.
- Composite Removals - best removal ability: multi-media filtration followed by activated carbon; intermediate removal ability: sedimentation; flocculation/-sedimentation; multi-media filtration; flocculation/sedimentation followed by multi-media filtration; multi-media filtration followed by ozonation; flocculation/sedimentation followed by multi-media filtration and activated carbon; and least removal ability: multi-media filtration with precoagulation.

It was concluded from the study[12] that multi-media filtration of secondary effluents followed by activated carbon treatment provided the best overall removal efficiency for toxic compounds as measured by fish and algae bioassay tests.

2.5.2 Air Emission Treatment. As previously discussed, possible emissions from textile processing include oil and acid mists, solvent vapours as well as dust and lints. A variety of techniques may be used to abate these types of air pollution. The abatement techniques are incineration, dry collection, adsorption and wet scrubbing.

Incineration employs high temperatures to destroy the pollutant and is the most reliable method of pollution abatement. Nevertheless, the high energy required makes it the most costly method as well and is not preferred for low volume emissions such as those from textile processing. However, incineration may be used for destruction of previously concentrated exhausts such as steam-stripped solvents from carbon solvent recovery beds or lint laden air from blow-down of lint filters.

In Dry Collection pollutants are collected in a relatively concentrated dry form for reuse or disposal. This method includes:

- Cyclone separation which employs centrifugal force to settle/remove coarse particles and mists (15 to 40 μm in size) from a gas stream.
- Filtration which is used for the removal of particulate and/or freely flowing oils. This includes bag house and mist eliminator. Bag house is used for the collection of dry dusts down to submicrometre range with 99+% efficiency. Fibre mist eliminator is used to remove droplets; collection efficiency for droplets above 3 μm is usually 100% while for droplets smaller than 3 μm is 95 to 99+%[13].
- Electrostatic precipitation which can be used for collection of particulate down to 0.1 μm with 95 to 99+% efficiency[13]. Exhaust air is first passed through an ionizing grid where the dust and droplets receive a positive charge causing them subsequently to be attracted to negatively charged collection plates. Freely flowing oil drops will coalesce on these plates and run off into a collection device while dust will remain on the plates from which they must be removed by periodic washing or rapping.

Adsorption removes gaseous pollutants from exhaust air by selective adsorption onto solids, e.g., the use of activated carbon to remove organic solvents from air emissions. If the system is sized and operating properly, it is possible to reduce exhaust concentration to less than 1 ppm.

Wet Scrubbing uses a liquid (water, an aqueous solution or slurry of chemicals) to wash, and thus remove, pollutants from a gas stream. The disadvantage of this method is that the pollutants are collected in a liquid creating a water pollution problem. However, if the existing effluent treatment facilities have the capacity to handle the additional load produced by the scrubbers, or if pollutants can be easily removed from the water by filtration, oil skimming, etc., wet scrubbing is a feasible method to reduce/eliminate organic vapours, oil mists or acid mists from emissions.

2.5.3 Solid Waste Disposal. Solid wastes from textile processing include screened or settled fibres, fabric cuttings, wastewater treatment sludges and latex wastes. For those that are not considered hazardous (e.g., screened/settled fibres and fabric cuttings) they require no treatment and can be disposed in municipal landfill sites. For those that are potentially hazardous (e.g., sludges and latex wastes) special techniques have to be employed for their treatment and disposal. Sludges are generally dewatered and then disposed of. Methods of sludge dewatering include:

- dry beds which dry sludges on open or uncovered sandbeds;

- dry lagoons which dry sludges in a lagoon with dry sludges being periodically removed;
- vacuum filtration which dewaters sludges under applied vacuum by means of a porous medium;
- centrifugation which operates by feeding a sludge through a stationary feed pipe and by settling solids out against the bowl wall by centrifugal force; and
- pressure filtration which uses plate and frame filter press to separate solids from the water.

Ultimate disposal of sludge includes spray irrigation, landfill and incineration, while disposal of latex waste may be by landfill (after treatment to eliminate the toxicity or immobilize the toxic components) or incineration. However, the selection of treatment and disposal method for these potentially hazardous wastes depends on the environmental condition as well as the cost option. For plants producing only a small quantity of solid hazardous wastes during normal operation, which is the case for most of the textile mills, the widely adopted method is to contract a hazardous waste disposal firm to truck the wastes away and carry out the treatment and disposal off-site.

3 ENVIRONMENT CANADA SURVEYS

3.1 The 1973/74 Survey

Environment Canada began developing liquid effluent regulations and guidelines for wet processing textile mills in the 1970s. The 1973/74 survey was carried out in conjuction with the regulation development program. Information was gathered on processing operations, water usage, effluent contaminant levels and existing waste treatment practices. Data acquisition was accomplished by means of distributing a questionnaire to a list of companies provided by the Canadian Textile Institute. A response to the questionnaire was obtained from approximately 60% of those companies surveyed. At the time of the survey (1973/1974) there were approximately 780 plants manufacturing textiles in Canada; about 94% of these plants were located in the provinces of Quebec and Ontario.

Among companies replying to the questionnaire, 118 indicated that they had wastewater effluents; of those, 67 were located in Quebec, 46 in Ontario and three in B.C. and three in Nova Scotia. The total annual production from these 118 mills was approximately 3×10^8 kg textiles. The largest 10% of these mills manufactured 45% of the textiles.

Although data obtained from this survey are outdated, some may be useful as references and are given briefly in the following[19].

3.1.1 Water Usage. Data on water usage are summarized in Figure 2, while water usage (in L/1000 kg of product) for different wet processes is:

- Wool Finishing: up to 530 000,
- Woven Fabric Finishing: up to 440 000,
- Knit Fabric Finishing: up to 370 000,
- Carpet Finishing: up to 210 000,
- Threads, Yarns and Fibres: up to 170 000, and
- Commission Dyeing: up to 370 000.

3.1.2 Effluent Discharges. Most of the mills discharge their effluent to a municipal sewer (94 out of the 114 mills surveyed); details of the breakdown are:

- 45 mills discharged to a municipal system without treatment facilities;
- 11 mills discharged to a municipal system with primary treatment;
- 38 mills discharged to a municipal system with secondary treatment;

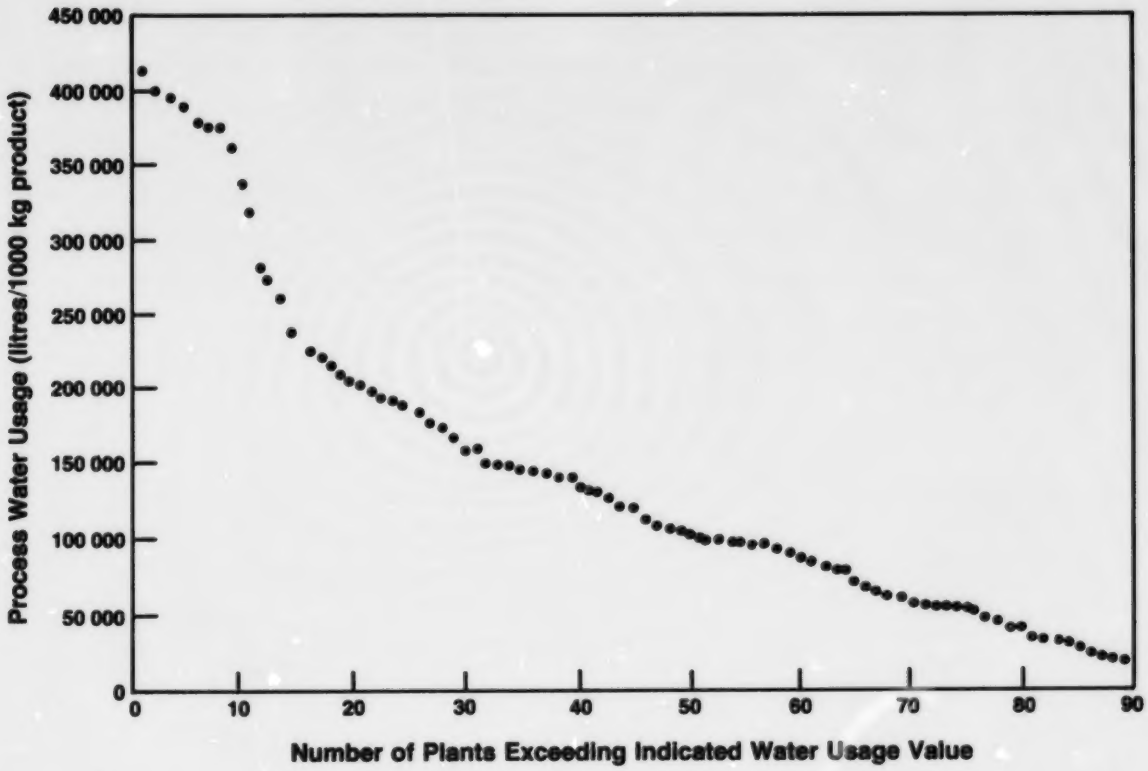

FIGURE 2 WATER USAGE IN THE TEXTILE INDUSTRY (1973/74 survey)

- 17 mills discharged to a natural watercourse without treatment; and
- three mills discharged to a natural watercourse with some forms of treatment (neutralization, chemical precipitation and extended aeration.

3.1.3 Contaminant Levels. About half of the returned questionnaires contained data on contaminant levels in wastewaters. Summaries of the pollution loading (in kg/1000 kg of product) for BOD, COD and TSS are shown in Figures 3 to 5 where the abscissa shows the number of mills exceeding the value given in the corresponding ordinate. Several mills reported analytical data on phenols and certain metal pollutants; these are:

- a mill processing (bleaching and dyeing) threads discharged 450×10^3 L/day of process effluents which contained 0.053 mg/L of phenols, 0.2 mg/L of chromium (Cr), 0.5 mg/L of copper (Cu) and 0.4 mg/L of zinc (Zn).

- a mill producing yarns discharged 550 x 10^3 L/day of process effluents which contained 0.2 mg/L of Cr, 0.5 mg/L of Cu and 0.3 mg/L of Zn.
- a woven fabric finishing mill discharged 2340 x 10^3 L/day of process effluents which contained 0.025mg/L of Cr, 0.23 mg/L of Cu and 0.46 mg/L of Zn.
- a mill producing fibres (scouring, spinning and fibre preparation) discharged 0.58 x 10^6 L/day of effluents which contained 40 mg/L of phenols.

3.1.4 Data on Selected Mills. Data obtained from this survey for a few selected mills, which were the subject of a "detailed survey" in 1981/82 and/or 1985/86, are given in Table 16.

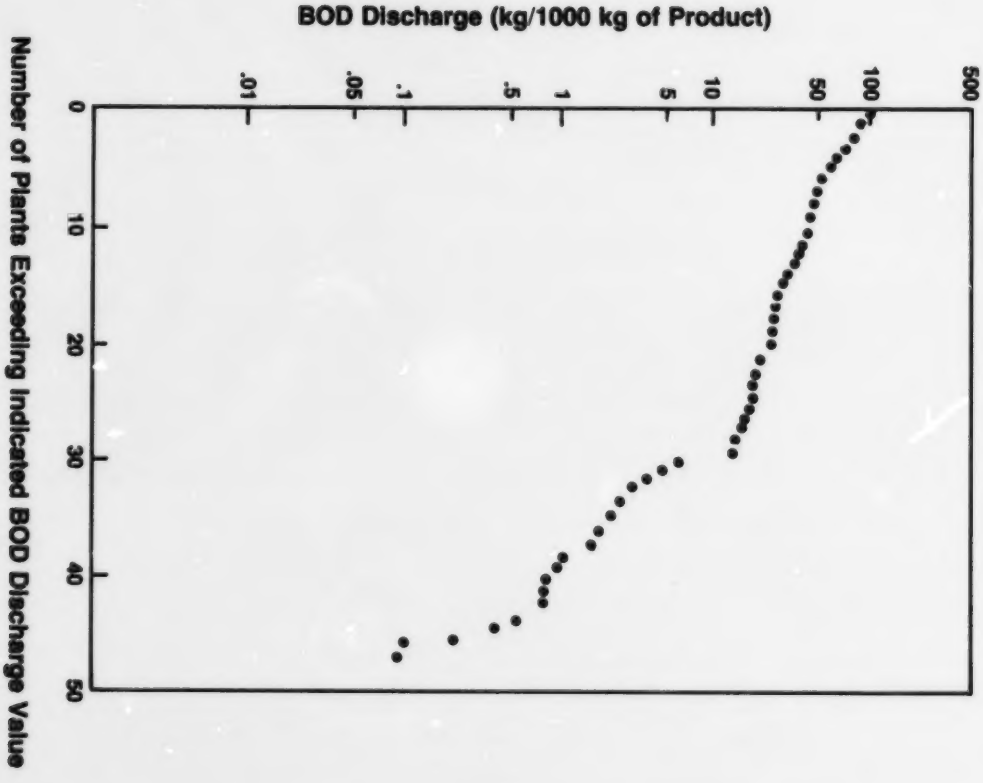

FIGURE 3 BIOLOGICAL OYGEN DEMAND (BOD) DISCHARGE FROM THE TEXTILE INDUSTRY (1973/74 survey)

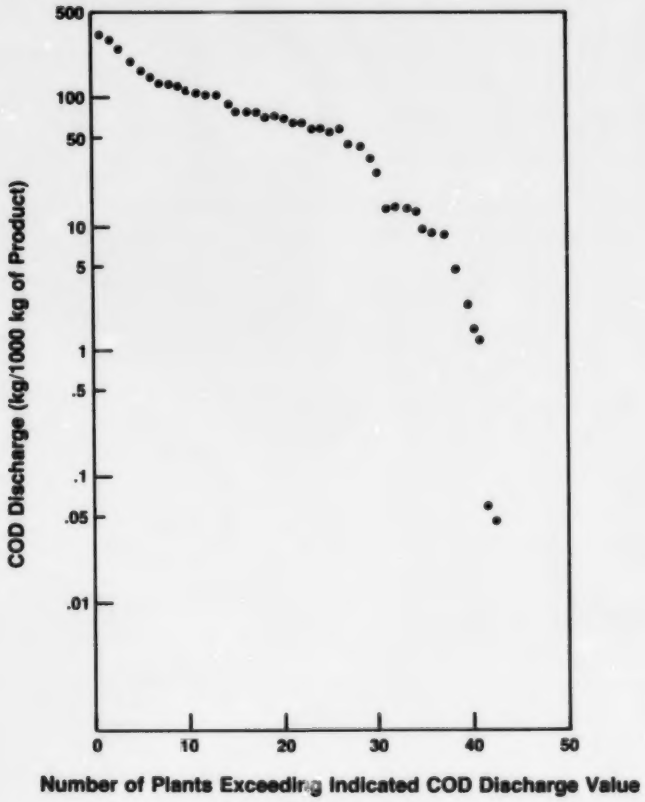

FIGURE 4 CHEMICAL OXYGEN DEMAND (COD) DISCHARGE FROM THE TEXTILE INDUSTRY (1973/74 survey)

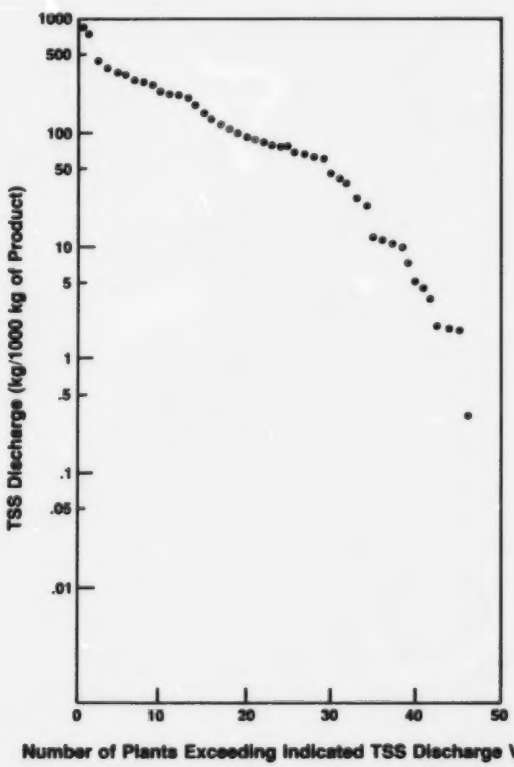

FIGURE 5 TOTAL SUSPENDED SOLIDS (TSS) DISCHARGE FROM THE TEXTILE INDUSTRY (1973/74 survey)

TABLE 16 DATA ON SELECTED MILLS (1973/74 survey)

	Processes	Water Use (L/100 kg of product)	Wastewater	Pollution Loading			
				BOD	TSS	Oil and Grease	COD
MILL A- woven fabric dyeing and finishing	-desizing, weaving mercerizing, scouring, bleaching, dyeing, printing and finishing	$196x10^3$	-discharged to a river without treatment; consisted of $18x10^6$ L/day of process effluents and $3.6x10^6$ L/day of cooling water	$10x10^3$ kg/day (99 kg/1000 kg of product)	$4.5x10^3$kg/day (23 kg/1000 kg product)	910 kg/day (4.4 kg/1000 kg of product)	
MILL B- woven fabric dyeing and finishing	-desizing, weaving mercerizing, scouring, bleaching dyeing and finishing	$197x10^3$	-discharged to a river after biological treatment (extended aeration lagoon) with a flow of 9.8×10^6 L/day	3300 kg/day* 780 kg/day**	1345 kg/day* 99 kg/day**		6600 kg/day* 5700 kg/day**
MILL C- knit and woven fabric dyeing and finishing	-knitting, weaving, scouring, fulling bleaching, dyeing printing and finishing	$390x10^3$	-discharged to a river after treatment (chemical precipitation, pH control and aeration) with a flow of $3x10^6$ L/day	6.3 kg/day** (8.1 kg/1000 kg of product)**	26 kg/day**		
MILL D- carpet finishing	-tufting, dyeing, printing and finishing	$83x10^3$	-discharged to the municipal system after solids removal; consisted of $2.2x10^6$ L/day of process effluents and $0.9x10^6$ L/day of cooling water	1175 kg/day (19 kg/1000 kg of product)	102 kg/day (40 kg/1000 kg of product)		3680 kg/day (62 kg/1000 kg of product)

* - before treatment
** - after treatment

3.2 The 1981/82 Survey

The 1981/82 survey consisted of two parts: a wet textile mill survey, and a toxics screening of textile mill effluents.

The wet textile mill survey was carried out by a contractor, IEC International Environmental Consultants Limited[3]; it included an industry overview and a detailed survey of six selected mills. The detailed survey included an inventory of chemicals used, a review of the wastewater treatment technology and an analysis of wastewater samples for pH, BOD, COD, TSS, methylene blue active substances (MBAS, an indicator for anionic surfactant levels), non-ionic surfactants content, fish toxicity and colour. The survey was conducted by a review of available literature as well as site visits to selected plants.

The toxics screening was mainly carried out by Environment Canada's Atlantic Region Laboratory and involved two other analytical laboratories (i.e, WTC laboratory and KER laboratory). Twenty effluent samples from six selected textile mills (the same six selected for the wet textile mill survey) were analyzed for a number of selected EPA organic priority pollutants. These pollutants were those which would likely be found in

textile effluents, phenol, chlorophenols, nitrophenols, chlorobenzenes, chlorinated ethers, chloro-dienes, polynuclear aromatic hydrocarbons and phthalate esters. The analytical method used was developed from a protocol evaluation carried out earlier[4].

Approximately 150 mills were identified as utilizing or potentially utilizing wet unit processes. The majority of these plants were located in the provinces of Quebec and Ontario. Two-thirds of these identified mills could be grouped into four processing categories: woven fabrics dyeing and finishing; knit fabrics dyeing and finishing; commission dyeing; and carpet finishing. The major unit processes used were: fabric dyeing in atmospheric manually controlled becks or winches, or in continuous ranges; yarn dyeing in pressurized, package dyeing vessels; washing or scouring in atmospheric becks or winches and finishing by padding or calendar rolls.

The six mills selected for detailed studies were representative of Canadian wet processing operations within weaving, knitting, wool finishing and carpet finishing.

3.2.1 Data on Individual Mills.

Mill A. This is a fully integrated mill producing woven fabrics of cotton, polyester and blends. In addition to bulk fabrics of corduroy, denim, printed, plain, white and greige goods, the plant produces some consumer goods. Processes used at the mill include yarn spinning, weaving, enzyme desizing, mercerizing, scouring, bleaching, dyeing, roll or screen printing and finishing.

Water use was about 170 x 10^3 L/1000 kg of product, while chemicals used included naphthol, pigment, direct, reactive, sulphur, soluble and insoluble vat dyes, acetic acid, surfactants, hydrogen peroxide, biophenyl disperse dye carriers, salt, sodium hydrosulphite, caustic soda, starches and various resins and other finishing chemicals.

Wastewater treatment at this mill consisted of screening and biological treatment (activated sludge, 20-hour retention) followed by clarification and discharge to a river. In the 1974/75 survey, this mill had not yet installed such wastewater treatment facilities.

With the exception of TSS and colour absorbance, the extended aeration activated sludge treatment provided from 50% to 98% reductions in the concentrations of the parameters and produced a non-toxic effluent.

Mill B. This is a woven fabric finishing mill that processes cotton and polyester fabrics or blends. Processes used include desizing, caustic scouring, peroxide bleaching, mercerizing, continuous, pad and jig dyeing, and finishing.

Water use at the time of the survey was about 330 x 10^3 L/1000 kg of product. Chemicals used included caustic soda, hydrogen peroxide, acetic and sulphuric acids, surfactants, acid, vat, sulphur, reactive and naphthol dyes, sodium hydrosulphite and various resins for finishing.

Wastewater treatment consisted of screening and secondary treatment in a mechanically aerated lagoon (five-day retention) and discharged to a river. No primary treatment or secondary clarification was practised.

The percent reductions probably do not reflect the real picture since the five-day retention in the lagoon precludes a true comparison of the values.

Mill C. This was a knit fabric finishing mill which manufactured and finished knit and woven fabrics of polyester, wool and cotton (knits goods were 2/3 of annual production). Processes included: scouring, fulling, mercerizing, bleaching, dyeing, printing, brushing, shearing, napping, softening, waterproofing, fireproofing and permanent press. Both yarns and fabrics were dyed in the mill which was closed in 1984.

Water use was about 390 x 10^3 L/1000 kg of product, and chemicals used included sulphuric and acetic acid for pH adjustment in dye baths, sodium chloride as a dye leveller, detergents for scouring, surfactants in dyeing, reactive and disperse dyes, and disperse dye carriers and various finishes.

Wastewater treatment consisted of flow equalization (1/2-day retention), chemical coagulation (lime, ferric sulphate and polymer addition), clarification (1/2-day retention), equalization in a mechanically aerated lagoon (one-day retention), and final clarification in a settling pond (1/2-day retention) before discharge over a V-notch weir to a river. Sludge from chemical coagulation was pumped to dewatering tanks and to drying beds.

It is noted from the analytical data that light absorbance is drastically reduced after primary treatment by lime, ferric sulphate and polymer addition, coagulation and settling. Also, a non-toxic effluent was produced after primary treatment. Reductions >50% were achieved for nonionic surfactants, anionic surfactants (measured by MBAS) and BOD. Overall treatment efficiencies exceed 75% for all parameters except TSS indicating a well operated treatment system.

Mill D. This is a carpet finishing mill that manufactures nylon and nylon/polyester carpets. Processes used at the mill include: tufting, beck and continuous dyeing, rotary and flat-bed screen printing.

Chemicals used in significant quantities include: acid, pre-metallized and disperse dyes, surfactants, acetic and sulphuric acids, disperse dye carriers, dye thickeners (gums) and latex. Water use is approximately 115 000 L per 1000 kg of product.

This mill has three wastewater discharges. A low flow, low pollution load stream flowed from the backing area. Latex recovery is practised in this area of the plant by settling effluent in a series of tanks, recovering the settled latex and discharging a negligible volume of effluent. Effluent from the rotary printer area passes through coarse screens into a settling tank and discharges to the municipal sanitary sewer system. Effluent from the flat-bed printer, the manually controlled atmopsheric becks and continuous dyer flows to a small settling tank and is then pumped through a hydrasieve before being discharged to the municipal sanitary treatment system.

Mill E. This is an integrated carpet finishing mill that produces carpets of nylon and polyester and blends (2/3 of production was nylon). Processes used include: blending, carding, spinning/twisting, tufting, dyeing and printing.

Process chemicals used in significant quantities include acid and disperse dyes, acetic acid for pH control in becks, Glauber's salt as a dye leveller for acid dyes, disperse dye carriers, and surfactants as wetting agents in dyeing. Water use is approximately 108 000 L per 1000 kg of product.

This mill has two wastewater discharges; the major flow was from the dyeing area and a small intermittent flow exiting the backing area. The stream from the backing area flows to a settling pit where solids are deposited and overflow is directed to the sanitary sewer. Sludge from the pit is hauled to an approved industrial waste landfill. Waste flows from the continuous and beck dyeing area is collected in an in-ground holding tank, pumped through a heat exchanger to preheat boiler feed water, then through a vibrating screen for solids removal and discharged to the municipal sanitary sewer.

Mill F. This is an integrated finishing mill that manufactures and finishes wool and blended wool fabrics. The primary fibres finished are wool and polyester. Principal processes used are light scouring, slashing, spinning, fulling, carbonizating, bleaching, stock, yarn and fabric dyeing, and finishing.

Chemicals used in significant quantities include acetic acid for pH adjustment in dyeing operations, disperse dyes for polyester dyeing, carriers for disperse dyes, acid and pre-metallized dyes for wool dyeing, Glauber's salt for acid dye levelling, hydrogen peroxide for bleaching, detergent for scouring, ammonia as a scouring assist agent,

lubricating oils in the spinning department and sulphuric acid for carbonizing. Water used is about 250 000 L/1000 kg of product.

Wastewater treatment consists of fine, vibratory screening (hydrasieve) and flow equalization. Detention time in the equalization tanks is approximately one day and effluent from the tank flowed to a municipal wastewater treatment system. The basic primary treatment scheme effected a 30% reduction in BOD and COD, a 30% to 40% decrease in light absorbance and an 80% decrease in fish toxicity.

A summary of analytical results for all mills studied is found in Table 17.

TABLE 17 ANALYTICAL RESULTS FOR MILLS (1981/1982 survey)

	pH (units)	BOD (mg/L)	COD (mg/L)	TSS (mg/L)	MBAS (mg/L)	Nonionic Surfactant		Fish Toxicity 96-h LC_{50}(%)	Colour (absorbance)
						Linear Alcohol (mg/L)	Ethoxylated Nonyl Phenol (mg/L)		
Mill A									
Raw Waste	4.8	1030	1860	75	2.3	1000	350	45 ± 3	0.06
Final Effluent	9.1	190	350	80	0.9	330	170	100	0.02
Percent Reduction	-	81	81	-	61	67	51	-	67
Mill B									
Raw Waste	12.2	730	1970	280	3.9	1130	280	46 ± 3	0.09
Final Effluent	11.7	310	1100	320	1.7	1400	400	80 ± 16	0.08
Percent Reduction	-	58	44	-	56	-	-	-	11
Mill C*									
Raw Waste	9.2	36	210	22	2.7	190	150	25	0.6
Primary Effluent	11.95	12	135	19	1.0	60	70	100	0.03
Percent Reduction Primary	-	67	36	14	63	68	53	-	95
Lagoon Final Effluent	11.15	4	52	11	0.6	10	20	100	0.02
Percent Reduction Lagoon	-	67	62	42	40	83	71	-	33
Overall Percent Reduction	-	89	75	50	78	93	87	-	97
Mill D									
Continuous Dyer, Beck Flatbed Effluent (after settling and screening)	7.5	205	1290	39	2.9	1030	260	6.9 ± 1.0	0.2
Rotary Printer Effluent (after settling and screening)	8.1	72	630	16	1.4	310	170	8.8 ± 1.3	0.1
Mill E									
Dye Waste (after screening)	6.9	340	1250	4	16.5	110	270	8.8 ± 0.4	0.2
Backing Area (after settling)	7.1	70	2185	270	1.3	Not determined	Not determined	60 ± 15	2.1
Mill F									
Raw Waste	6.9	470	1480	46	3	1670	350	2.8 ± 0.4	0.365
Plant Effluent (after screening and equalization)	7.5	310	995	62	2.7	980	230	14 ± 4.0	0.239
Percent Reduction	-	34	33	-	10	41	34	-	34

* Raw Waste - sampled from 0.5 day retention equalization basin
Primary Effluent - sampled after lime, ferric sulphate and polymer addition and settling
Fish Toxicity Test-performed after pH adjustment to range 6 to 9, if required.

3.2.2 Chemical Inventory. A chemical inventory representing a reasonable cross-section of chemicals in use at wet processing textile mills was developed for the survey.

Over 400 chemicals were identified that were consumed in quantities greater than 2000 kg/year. These chemicals were classified into 18 categories as shown in Table 18 which also summarizes total annual use of chemicals in each of the categories and the number of chemicals in each class for the six mills surveyed.

TABLE 18 SUMMARY OF CHEMICAL INVENTORY FROM THE 1981/82 SURVEY

Classification	Approximate Annual Use (kg/yr)	Number of Compounds in Class
1. Vat Dyes	168 000	24
2. Sulphur Dyes	583 000	19
3. Naphthol Dyes	71 000	15
4. Basic Dyes	2 000	1
5. Finishes	4 100 000	87
6. Acids/Alkalies	6 260 000	12
7. Detergents/Soaps/Auxiliaries	250 000	14
8. Dye Auxiliaries	4 200 000	91
9. Bleaches and Assists	250 000	3
10. Disperse Dyes	208 000	38
11. Lubricating Oils	60 000	11
12. Miscellaneous	140 000	12
13. Dye Carrier	370 000	6
14. Softeners	145 000	15
15. Reactive Dyes	23 000	10
16. Direct Dyes	3 000	2
17. Acid and Pre-Metallized Dyes	38 000	20
18. Pigment Dyes	180 000	28

3.3 The 1985/86 Survey

The 1985/86 survey was carried out to update the existing database by surveying selected textile mills as well as sampling/analyzing effluent samples from selected textile mills for a number of parameters (e.g., conventional pollutants, metals, EPA organic priority pollutants and effluent fish toxicity). (Detailed sampling and analytical procedures are given in Appendix B.) The data updating exercise was accomplished by visiting the selected plant sites and completing a questionnaire with a representative from the mill. The effluent sampling and analysis was included as part of a study on nonionic surfactants as textile processing is the largest industrial user of those chemicals. The study was conducted by Beak Consultants Limited on contract with Environment Canada with the objective of assessing the fate and effects of nonionic

surfactants in the aquatic environment; it included the sampling and analysis of effluent samples from five selected textile mills[20].

Although there have been many plant closures since 1982, some of the general statistics for this industry remain approximately the same, e.g., 55% of the mills are located in Quebec and 40% in Ontario; the largest 10% of the mills produce more than 45% of the textiles; approximately 20% of the mills use wet processing and about half of these belong to the woven fabric and knit fabric dyeing and finishing subcategories; more than 80% of the wet processing mills discharge their effluents to a municipal system and about 50% of those discharging directly to a natural watercourse have wastewater treatment facilities. However, based on data obtained from the selected mills, water usage and chemical use per unit of production as well as contaminant levels in effluents are generally decreased as compared with data from previous surveys.

The questionnaires used in this survey included sections on air emissions and solid wastes (see Appendix D). However, little information was obtained regarding these two waste streams. Most of the mills surveyed (7 out of 10) indicated that they had air emissions of particulate consisting mainly of fibre dust/lint and that bagfilters, suction/air filters or cyclones were used to control such emissions. Four mills indicated that they had emissions of solvent vapour; only one of them, a carpet finishing mill, had installed control devices (scrubbers). Two mills had emissions of oil mists; one of them, a commission dyeing plant, used scrubbers to control the emission. Other emissions mentioned in the completed questionnaires are ammonia and vapours of sodium hydrochlorite/hydrosulphate.

Nine out of the ten mills surveys produced solid wastes. The two most common wastes were screened/settled fibres and waste fabrics/cloth. The screened/settled fibres went to dumping sites, while the waste fabrics/cloth were sold/given away or land disposed. Half of the mills surveyed had wastewater treatment; two used biological processes, two had equalization and one had sedimentation. One of the biological treatment plants produced some 10 m^3/week of sludges (with a solids content of about 0.8%) which was at the time discharged to a river and will be discharged to the local municipal sewage treatment plant (STP) in a future arrangement. The other biological treatment plant, a 5-day retention mechanically aerated lagoon, has so far produced no sludge. The mill with sedimentation treatment produced 27 m^3/month of sludges which were land disposed. The two mills with equalization tanks produced an insignificant amount of sludges (the tanks were cleaned only once every year or every two

years) which were land disposed. Other wastes mentioned in the completed questionnaire were waste-skimmed oil from a commission dyeing plant, latex wastes from a carpet finishing mill and waste polyvinyl alcohol (PVA) foam from a knit fabric mill. The skimmed oil went to an incinerator, the latex wastes were landfilled and the waste PVA foam was land disposed.

3.3.1 Mill Wastewater Data.

Mill A. Mill A, a woven fabric dyeing and finishing mill, practices the same wet processes previously described. However, production has been cut back to about 25% of the 1982 level.

Chemicals used are similar to those used in the 1980/81 survey, e.g., disperse, reactive, developed, sulphur and vat dyes, caustic soda, hydrogen peroxide, acetic and sulphuric acids, surfactants, salts, starches, resins and various finishing chemicals.

Water use is about 9.9×10^6 L/day while mean effluent flow is 9.2×10^6 L/day. Wastewater treatment, as described previously, consists of screening, pH adjustment and activated sludge treatment (20-hour retention) followed by clarification and discharge to a river. Effluent samples were collected from the treatment plant influent and clarifier overflow. Two samples of return sludge were also taken from the sludge return line but failed to yield any analytical results due to a highly dilute solids content. It should be noted that prior to the sampling, there was a malfunction in the effluent pH adjustment system, resulting in a drop of the pH to about 3.5 (normal pH should be around 8) causing a substantial loss of biological activity in the aerated basin.

The BOD and COD results in Appendix C (Table C-7) show that biological activity in the aeration basin had effectively ceased. Comparison of the return sludge concentrations on the first and last days of sampling indicate that biomass was being continuously lost from the system, without BOD utilization to replenish the biomass. Metals concentrations in the effluent are higher than in the influent, presumably because of biomass carryover. Nonetheless, effluent metals levels are low, with the exception of iron, which originated from the coagulant addition. Mercury and arsenic levels are about an order of magnitude above their detection limits. The mercury may originate from caustic used in the plant (only if mercury cell caustic is available). There is no obvious source for the arsenic in plant operations.

It is evident that despite the non-viable biomass, significant removal of the volatile organics is still occurring (Table C-8). This is assumed to be by air stripping. No acid fraction compounds were found in the influent and effluent, other than phenol which

was found in trace amounts to 30 µg/L. Only four base/natural extractable organics were found in the raw and treated wastewaters and at similar levels as would be expected with the absence of biological activity.

Some data obtained from the completed questionnaires are found in Table 19.

Mill B. At Mill B, a woven fabric dyeing and finish plant, wet processes involve: desizing, caustic scouring, peroxide bleaching, mercerizing, continuous, pad and jig dyeing, screen print and finishing.

Chemicals used include caustic soda, hydrogen peroxide, acetic and sulphuric acids, surfactants, detergents, disperse, sulphur, vat, reactive and indigosol dyes, salts, various resins and finishing chemicals.

Water use is 9×10^6 L/day and effluent discharge is about 8.2×10^6 L/day. Wastewater treatment consists of screening and secondary treatment in a mechanically aerated lagoon (5-day retention) and discharge to a river. Samples were collected from lagoon influent and effluent. Two sludge samples were also taken near the lagoon influent and effluent.

Analytical results for Mill B show about 80% reduction in BOD but only 30% reduction in COD (Table C-9). Effluent TSS levels are similar to those in the influent since clarification is not practised. Metal levels are low overall with a number reported as less than the detection limits.

The organic priority pollutants found in the effluents are summarized in Appendix C (Table C-10). A total of nine volatile organic compounds were found in the influent, and only six of these were found in the lagoon effluent, at substantially reduced concentrations. Removal of these organics appeared to be in excess of 60%. The mechanism of removal, biodegradation or air stripping, cannot be determined from the data. However, given that 80% BOD removal was achieved, and many of these compounds are degradable, both mechanisms are probably important. Of the acid fraction compounds, phenol and pentachlorophenol were found at levels less than 15 µg/L. The compound p-chloro-m-cresol was found at higher levels in the effluent (about 250 µg/L) than in the influent (about 60 µg/L). Only three base neutral compounds were found in the lagoon influent; two of which were found in the effluent.

Sampling and analyses from a separate study carried out by an Environment Canada Regional Office are given in Table C-12. The BOD reduction after treatment was 85% while COD reduction was 40%; "oil and grease" also showed a reduction of 60% after treatment.

TABLE 19 EFFLUENT QUALITY FROM NORMAL OPERATION (obtained from questionnaires)

Parameters*	Mill A	Mill B	Mill D	Mill E	Mill F	Mill H	Mill I	Mill J
BOD	50	30 to 50	158 to 203	72 to 105	150 to 350	80 to 150	200 to 450	300
COD	600	400 to 500	391 to 1419	630 to 1290	995	50 to 90		800
TSS	20 to 60	150 to 250	36 to 1810	16 to 39	62		10 to 95	20
pH (units)	8 to 9	9 to 11	6.5	7.5 to 8.1	7.5	7.5 to 10	7 to 8	6.5 to 8.0
Oil and Grease	8 to 12	24						50 to 60
Organic Nitrogen	15							
Phosphorus (as P)	0.3					2.2		
Phosphorus (as PO_4)		3.5						
NH_3-N		1.5						
Cd						<0.01		
Cr						<0.01		
Cu						0.3		
Ni						<0.01		
Zn						0.3		
Phenol (µg/L							30 to 40	

* all parameters measured in mg/L excepted where indicated otherwise

Mill E. Processes involved at Mill E include: blending, carding, spinning, twisting, tufting, washing, dyeing, printing and finishing.

Process chemicals used in significant quantities include acid, cationic and disperse dyes, dye carriers, surfactants, acetic acid, Glauber's salt, softener and teflon antisoil finishing agents. Water use is about 2.3×10^6 L/day.

The mill has two wastewater discharges; the main flow consists of wastewaters from all processing areas except the latex backing. This effluent is screened to remove fibres and piped to a foam pit before being discharged to a municipal sewer. Wastewater from the latex backing area is settled in a series of concrete tanks; overflow from the tanks joints the main effluent and discharges to the sewer. Samples of the main effluent as well as the latex effluent were collected and the analytical results are found in Appendix C (Tables C-13 and C-14). It is seen that the latex effluent is much more contaminated. This stream, however, is very small compared to the main effluent discharge of some 2×10^6 L/day.

Mill F. Light scouring, slashing, spinning, weaving, bleaching, carbonizing, stock, yarn and fabric dyeing and finishing are the processes involved at Mill F. Water use averages 250×10^3 L/1000 kg of product.

Chemicals used in significant quantities include acetic acid for pH adjustment in dyeing operations, disperse dyes for polyester dyeing, carriers for disperse dyes, acid and pre-metallized dyes for wool dyeing, Glauber's salt for acid dye levelling, hydrogen peroxide for bleaching, detergents for scouring, ammonia as a scouring assist agent, lubricating oils in the spinning department and sulphuric acid for carbonizing.

Wastewater treatment consists of fine screening and flow equalization (one-day detention); effluents from the equalization tank discharge to the municipal system with an average flow of 1×10^6 L/day. Samples of the bull screen effluent as well as the final effluent were collected and analyzed.

Analytical results for conventional pollutants, metals and organic priority pollutants are found in Appendix C (Tables C-15 and C-16). The table on organic priority pollutants includes only those compounds which were identified in two or more of the raw or equalized wastewater streams. The most significant compounds appear to be chlorinated solvents typically used as cleaning solvents and the substituted benzenes, toluene, xylenes, and ethylbenzene. There appears to be some reduction in concentrations from raw to equalized wastewater, probably due to volatilization from equalization tanks. Of the acid fraction compounds, only phenol and dimethyl phenol were found in measurable quantities. Traces of other phenols were occasionally found, though not with any consistency.

Mill G. This mill was not included in previous detailed surveys. It is a knit fabric dyeing and finishing mill and consists of two distinct operations: hosiery and underwear. The underwear mill processes primarily polyester/cotton, acrylics, nylons, rayon and wool. The dyes used in both operations are similar, including acid, direct, disperse, reactive and developed dyes. The hosiery mill uses a small amount of pre-metallized dyes as well.

Chemicals used include the dyes previously mentioned, caustic soda, acetic acid, hydrogen peroxide, sodium salts, surfactants and various finishing chemicals. Total water consumption is about 3.4×10^5 L/day.

Wastewaters from the underwear operation all flows to a main sewer which discharges directly to the city sewer with an average flow of 180×10^3 L/day. Wastewaters from the hosiery operation are collected in an equalization pit from which they overflow to the municipal sewer with an average flow of 120×10^3 L/day. Samples were collected from these two effluent discharges.

The analytical data for conventional pollutants and metals are presented in Appendix C (Table C-17). The hosiery mill had higher levels of ammonia, non-ionic surfactants, and total phenols than the underwear mill. The hosiery mill also had substantially higher levels of volatile and base/neutral organics (Table C-18). Only chloroform was detected in the underwear mill effluent, while a total of five volatile compounds were found in the hosiery mill effluent. All the volatile compounds found were chlorinated, and appear to be related to cleaning solvents. Of the acid fraction

compounds, only phenol and traces of 2-nitrophenol were found consistently. Phenol was found at concentrations up to 21.5 µg/L in the underwear mill effluent, and at concentrations up to 58.6 µg/L in the hosiery mill effluent. Concentrations of 15.0 µg/L of 2-nitrophenol were found only in the hosiery mill effluent, but in all three samples. Significant concentrations of two phthalates were found in both effluents, while naphthalene and 1,4 dichlorobenzene were found only in the hosiery mill effluent. Despite the apparent similarity in the dyes used, there are clearly significant differences in the processes which result in different types and concentrations of organics in the effluent.

Mills D, H, I, J. These mills were not included in the detailed study of sampling and analysis of pollutants in effluent discharges. However, they were included in the survey and each had completed the questionnaire. Data obtained are given briefly in the following.

- Mill D: Processes involve tufting, beck and continuous dyeing, flat-bed and rotary screen printing and finishing. Chemicals used in significant quantities include acid, cationic and disperse dyes, surfactants, dye carriers, latex and finishing chemicals. Wastewaters were treated by equalization, screening and sedimentation before discharge to the sewer with an effluent flow of about 5×10^6 L/day.

- Mill H: This is a knit fabric dyeing and finishing mill producing circular knitted fabrics, underwear and sportwear. Processes involve knitting, scouring, bleaching, dyeing and finishing. Chemicals used in significant quantities are disperse, sulphur and reactive dyes, acetic acid, caustic soda, hydrogen peroxide, surfactants, sodium salts and finishing chemicals. Water use averages 1.5×10^6 L/day. Effluents were screened and then discharged to the municipal sewer.

- Mill I: This is a knit fabric dyeing and finishing mill producing pile fabric and pile products. Processes involved are knitting, scouring, bleaching, and dyeing. Chemicals used in significant quantities are acid, cationic and disperse dyes, surfactants, hdyrogen peroxide, latex and finishing chemicals. Water use is about 0.2×10^6 L/day (50% process water). Wastewaters were screened, settled and then discharged to the municipal system.

- Mill J: This is a commission dyeing mill involving dyeing and finishing of woven and knit fabrics. Chemicals used in significant quantities are acid, cationic, direct and disperse dyes, surfactants, acetic acid, caustic soda, softeners, optical brightness and resins. Effluent discharge is about 1.8×10^6 L/day (98% process wastewaters).

Data on effluent quality from these mills is found in Table 19.

4 ASSESSMENT OF THE ENVIRONMENTAL PROBLEMS

Results obtained from the surveys are analyzed in this chapter. The environmental problems associated with textile mill discharges are also discussed.

4.1 Conventional Pollutants

Results of the surveys indicate that the loading of conventional pollutants such as BOD, COD and TSS is not related to plant size and production. The factors determining these pollution loads are type of processes, age of plant and state of technology. Figures 3, 4 and 5 of the 1973/74 survey show a break in the curve at 10,30 and 20 kg/1000 kg of product for BOD, COD and TSS, respectively. The break point separates plants which had dyeing and finishing operations and plants with only primary operations such as fibre preparation, spinning and weaving; the former (without any treatment) discharged BOD greater than 10 kg per 1000 kg of product, COD greater than 30 kg per 1000 kg of product and TSS greater than 20 kg per 1000 kg of product, while the latter generally discharged less.

Available concentration data and pollution loading for BOD, COD and TSS at mills included in the surveys are summarized in Tables 20 and 21. Table 21 also includes the U.S. EPA BPT limitations (21) as well as Environment Canada's 1978 Proposed Guidelines for comparison. (Complete U.S. EPA BPT and BAT limitations for the textile industry are given in Appendix E.)

From Table 20, it is seen that concentrations of BOD, COD and TSS have generally remained in the same order or decreased from 1981/82 to 1985/86, except for Mill A where the treatment system was not working properly during the 1985/86 sampling period. The limited data for the 1973/74 survey were calculated from the pollution loadings given in the returned questionnaire and appear to be on the lower side.

For Mills without secondary treatment and discharging to the municipal sewer (i.e., Mills D, E, F, G, H, I and J), the concentrations of BOD and TSS in their effluents were all within the limits of local municipal sewer by-laws which are 500 mg/L and 300 mg/L, respectively.

For Mills with a well-operated biological treatment system, the loadings of BOD and TSS were within or close to both the U.S. EPA BPT limits and Environment Canada's Proposed Guidelines. Mill C, which had chemical coagulation, aerated lagoon and clarification, produced an effluent with loadings of BOD, COD and TSS well below the U.S. EPA BPT limits and those set in Environment Canada's 1978 Proposed Guidelines.

TABLE 20 SUMMARY OF CONCENTRATION DATA FOR BIOLOGICAL OXYGEN DEMAND (BOD), CHEMICAL OXYGEN DEMAND (COD), AND TOTAL SUSPENDED SOLIDS (TSS)

	Concentration (mg/L)				
Mill/Parameter	1974/75 Survey**	1981/82 Survey	1985/86 Survey	1985/86 Reported Value ***	Remarks
MILL A					
BOD	185	19	500	50	- treatment system was not working properly during the 1985/86 survey
COD	-	350	1240	600	
TSS	83	80	190	20 to 60	
MILL B					
BOD	79	310	82	30 to 50	- the 1981/82 data appear to be too high
COD	581	1100	1101	400 to 500	
TSS	10	320	112	150 to 250	
MILL C					
BOD	21	4	-	-	- closed down in 1985
COD	-	52	-	-	
TSS	9	11	-	-	
MILL D*					
BOD	379	205/72	-	158 to 203	
COD	1187	1290/630	-	391 to 1419	
TSS	33	39/16	-	36 to 1810	
MILL E*					
BOD	-	340	320	72 to 205	- data from the main effluent
COD	-	1250	1000	630 to 1290	
TSS	-	4	23	16 to 32	
MILL F*					
BOD	-	310	210	150 to 350	
COD	-	995	500	995	
TSS	-	62	59	62	
MILL G* (Underwear)					
BOD	-	-	83	-	- not included in the 1981/82 survey
COD	-	-	630	-	
TSS	-	-	105	-	
MILL G* (Hosiery)					
BOD	-	-	71	-	- not included in the 1981/82 survey
COD	-	-	440	-	
TSS	-	-	63	-	
MILL H*					
BOD	-	-	-	80 to 150	- not included in the detailed surveys
COD	-	-	-	50 to 90	
TSS	-	-	-	-	
MILL I*					
BOD	-	-	-	200 to 450	- not included in the detailed surveys
COD	-	-	-	-	
TSS	-	-	-	19 to 95	
MILL J*					
BOD	-	-	-	300	- not included in the detailed surveys
BOD	-	-	-	800	
TSS	-	-	-	20	

* - primary treatment only; effluent discharged to municipal sewer
** - based on loading data given in returned questionnaire and converted to concentrations by calculation
*** - from returned questionnaire

TABLE 21 SUMMARY OF POLLUTION LOADING FOR BIOLOGICAL OXYGEN DEMAND (BOD), CHEMICAL OXYGEN DEMAND (COD) AND TOTAL SUSPENDED SOLIDS (TSS)

Subcategory/Mill	Loading (kg/1000 kg of product)		
	BOD	COD	TSS
Woven Fabric Finishing			
EPA - BPT Daily Maximum	6.6	60	17.8
- BPT Monthly Average	3.3	30	8.9
EPS - 1978 Proposed Guidelines	17.3 to 27.8	-	8
Mill A - 1973/74 Survey**	99	-	23
- 1981/82 Survey	4	73	17
- 1985/86 Survey **	72 (7.2)	180 (87)	27 (5.7)
Mill B - 1974/75 Survey	22	160	3
- 1981/82 Survey	47	165	48
- 1985/86 Survey	9.8	132	13
Knit Fabric Finishing			
EPA - BPT Daily Maximum	5.0	59.5	15.6
- BPT Monthly Average	2.5	38.3	6.9
EPS - 1978 Proposed Guidelines	17.3 to 27.8	-	8
Mill C - 1973/74 Survey	8.1	-	5
- 1981/82 Survey	1.5	20	4
*Mill G (Underwear) 1985/86 Survey	5.3	40	6.7
*Mill G (Hosiery) 1985/86 Survey	8.5	52	7.7
Wool Finishing			
EPA - BPT Daily Maximum	22.4	163.0	35.2
- BPT Monthly Average	11.2	81.5	17.6
EPS - 1978 Proposed Guidelines	31.2	-	8
Mill F - 1981/82 Survey	54	174	11
- 1985/86 Survey	66	158	18
Carpet Finishing			
EPA - BPT Daily Maximum	7.8	70.2	11.0
- BPT Monthly Average	3.9	35.1	5.5
EPS - 1978 Proposed Guidelines	23.3	-	8
Mill D - 1973/74 Survey	19	62	40
- 1981/82 Survey	10	67	2
Mill E - 1981/82 Survey	37	135	0.5
- 1985/86 Survey	25	68	0.5

* primary treatment only; discharged to municipal sewer
** no treatment was in place during the 1974/75 survey; treatment system was not working properly during the 1985/86 survey; values in brackets were calculated from reported concentrations

For Mills with only primary treatment and discharging to the municipal sewer, it is surprising to find that:

- both the underwear and hosiery operations of Mill G had loadings of BOD, COD and TSS all within the U.S. EPA BPT limits; the BOD and TSS loadings of Mill G also met Environment Canada's 1978 Proposed Guidelines;
- the wool finishing mill, Mill F, as well as the two carpet finishing mills, Mills D and E, all had a loading of TSS within or close to the U.S. EPA BPT limits; Mill D also met Environment Canada's Proposed Guidelines for BOD loadings.

Available data for pH and oil and grease are summarized in Table 22. All effluent discharges were within the desirable pH range of 6 to 9, except those from Mills B and C which were near 11. Normal discharges from Mill A should have a pH of 8 to 9 since the wastewater was neutralized with sulphuric acid to this pH value; the 10.3 value obtained in the 1985/86 survey was due to a malfunction in the acid dosing system.

The limited data on oil and grease show that Mill J, a commission dyeing plant, exceeded the limit of 15 mg/L (for mineral and synthetic oil) set by local municipal by-law. Mill B which discharged directly to a river, also had a reported oil and grease level in excess of the 15 mg/L limit.

Based on results of these surveys, conclusions regarding conventional pollutants in textile mill effluents are that:

- all mills discharged to a municipal sewer met the limits for BOD and TSS set by local municipal sewer by-law;
- mills with secondary treatment had loadings of BOD, and TSS (in kg per 1000 kg of product) within or close to the U.S. EPA BPT limits and the limits set by Environment Canada's 1978 Proposed Guidelines;
- mills with only primary treatment (screening) could have a loading of TSS within the U.S. EPA BPT limits as well as Environment Canada's Proposed Guidelines;
- most of the effluents from mills included in the surveys had a pH value within the range of 6 to 9;
- the level of oil and grease in some of the effluents would likely exceed 15 mg/L, the limit set by local municipal sewer by-laws for mineral and synthetic oil.

4.2 Priority Pollutants

The 1973/74 survey did not include contaminants such as those later known as priority pollutants. However, a few mills did report analytical data on phenols, chromium, copper and zinc which were found in their effluent discharges at concentrations from

TABLE 22 SUMMARY OF AVAILABLE DATA FOR pH AND OIL AND GREASE

Mill/Parameter	Concentration (mg/L for Oil and Grease) 1974/75 Survey	1981/82 Survey	1985/86 Survey	1985/86 Reported Value
Woven Fabric Finishing				
Mill A/pH	-	9.1	10.3	8 to 9
Oil and grease	16	-	-	8 to 12
Mill B/pH	-	11.7	10.6	9 to 11
Oil and grease	-	-	-	24
Knit Fabric Finishing				
Mill C/pH		11.1	-	-
*Mill G (underwear)/pH	-	-	9.2	-
*Mill G (hosiery)/pH	-	-	7.8	-
*Mill H/pH	-	-	-	7.5 to 10
*Mill I/pH	-	-	-	7 to 8
Wool Finishing				
*Mill F/pH	-	7.5	7.5	7.5
Carpet Finishing				
*Mill D/pH	-	7.5/8.1	-	6.5
*Mill E/pH	-	6.2/7.1	7.0	7.5 to 8.1
Commission Dyeing				
*Mill J/pH	-	-	-	6.5 to 8.0
Oil and grease	-	-	-	50 to 60

* discharged to municipal sewer

0.02 to 40 mg/L. The 1981/82 toxics screening identified ten organic priority pollutants in the effluents of the six mills selected to represent the four most common wet textile processing subcategories: woven fabric finishing, knit fabric finishing, wool finishing and carpet finishing. The results of the 1981/82 toxics screening are summarized in Table 23.

TABLE 23 ORGANIC PRIORITY POLLUTANTS FOUND IN TEXTILE MILL EFFLUENTS (1981/82 toxics screening)*

Sample	Compound Identified	Concentration Range (µg/L)
Wool Finishing Screen Effluent	phenol	33/65
	naphthalene	17/37
	di-n-butylphthalate	246
	di-n-octylphthalate	40
	bis(2-ethylhexyl)phthalate	206
Wool Finishing Final Effluent	phenol	57/63
	naphthalene	14/21
	di-n-butylphthalate	49
	di-n-octylphthalate	16
	bis(2-ethylhexyl)phthalate	74
Carpet Finishing Dye Wastewater	phenol	< 25/116
	4-nitrophenol	< 20/20
	1,2,3, trichlorobenzene	21/32
	naphthalene	139/132
	fluorene	22
	bis(2-ethylhexyl)phthalate	64
Woven Fabric Dyeing and Finishing Dye House Effluent	phenol	< 25/28/42
	naphthalene	< 2/10/12
	di-n-butylphthalate	< 2/10
	bis(2-ethylhexyl)phthalate	60/246
Woven Fabric Dyeing and Finishing Primary Effluent	pentachlorophenol	< 25/70
	naphthalene	21/16/29
	di-n-butylphthalate	< 2/28
	bis(2-ethylhexyl)phthalate	56/408
	n-nitrosodiphenylamine	< 10/16

* based on one sample; different values are analytical results from different laboratories

The 1985/86 survey included sampling and analysis of effluent samples from five selected mills for metal as well as organic priority pollutants. The results obtained are discussed in the following.

The U.S. EPA 1979 survey[12] identified over 100 compounds in secondary effluents from 44 textile mills. Of these, 17 organic priority pollutants, cyanide and 11 heavy metals were detected in concentrations of 10 µg/L or greater. Table 24 lists the pollutants, the number of mills whose effluents contained the pollutants and the concentration range detected.

TABLE 24 PRIORITY POLLUTANTS IDENTIFIED BY THE U.S. EPA IN SECONDARY EFFLUENTS FROM FORTY-FOUR TEXTILE MILLS

Pollutant	Number of Mills Pollutant Detected at Given Concentration	
	greater than 10 µg/L	less than 10 µg/L
acrylonitrile	1	N.I.
benzene	5	6
1,2,4-trichlorobenzene	10	N.I.
2,4,6-trichlorophenol	5	N.I.
parachlorometacresol	2	N.I.
chloroform	12	2
1-2-dichlorobenzene	4	5
ethylbenzene	19	4
trichlorofluoromethane	5	N.I.
naphthalene	15	7
N-nitrosodi-n-propylamine	2	N.I.
pentachlorophenol	10	2
phenol	25	4
bis(2-ethylhexyl)phthalate	27	N.I.
tetrachloroethylene	4	4
toluene	18	13
trichloroethylene	10	3
antimony	8	14
arsenic	11	N.I.
cadmium	1	N.I.
chromium	13	25
copper (raw waste)	30	N.I.
cyanide	2	42
lead (16 plants only)	6	10
mercury (38 plants only)	5	33
nickel	9	18
selenium	6	N.I.
silver	15	N.I.
zinc	44	0

N.I. - no information given

The results of the U.S. EPA 1979 survey and the results of the 1985/86 survey; are compared in Table 25 by wet processing subcategories. The EPA compounds for each subcategory were found half the time or less in the corresponding Canadian mills. On the other hand, there appeared to be more compounds present in Canadian mill effluents than in the U.S. At Mill F, three out of seven EPA compounds were found and an additional three compounds were found at concentrations greater than 10 µg/L. At Mill E, four out

TABLE 25 SUMMARY OF ORGANIC PRIORITY POLLUANTS IN TEXTILE MILL EFFLUENTS (1985/86 survey)

Subcategory	Compound	EPA (>10 µg/L)	EPS 1985/86 (µg/L)	
Wool Finishing (Mill F)	1,2-dichlorobenzene	x	ND	
	1,4-dichlorobenzene	x	1	
	bis(2-ethylhexyl)phthalate	x	40	
	ethylbenzene	x	8.6	
	naphthalene	x	8.6	
	pentachlorophenol	x	ND	
	trichloroethylene	x	1.1	
	1,1,1-trichloroethane	-	1	
	toluene	-	1	
	tetrachloroethylene	-	1.6	
	phenol	-	17.8	
	2,4-dimethyl phenol	-	15	
	di-n-butyl phthalate	-	158	
Carpet Finishing (Mill E)	chloroform	x	Tr to 6.1	(main and latex)
	naphthalene	x	10	(latex only)
	phenol	x	15	(main and latex)
	bis(2-ethylhexyl)phthalate	x	1 to 32.1	(main and latex)
	1,1,1-trichloroethane	-	ND to 1.1	(main and latex)
	toluene	-	Tr to 1.5	(main and latex)
	ethylbenzene	-	6.3	(latex only)
	1,4-dichlorobenzene	-	36	(latex only)
	1,2-dichlorobenzene	-	95	(latex only)
	pentachlorophenol	-	15	(main only)
Hosiery (Mill G)	acrylonitrile	x	ND	
	2,4,5-trichlorophenol	x	ND	
	chloroform	x	250	
	naphthalene	x	10.2	
	N-nitrosodiphenylamine	x	ND	
	phenol	x	34.9	
	bis(2-ethylhexyl)phthalate	x	2.8	
	tetrachloroethylene	x	1.2	
	1,1-dichloroethylene	-	13.9	
	1,1,1-trichloroethylene	-	31.7	
	1,4-dichlorobenzene	-	71.1	
	di-n-butyl phthalate	-	14.7	
	2,4-dichlorophenol	-	15	
	2-nitrophenol	-	15	
Knit Fabric (Mill G)	1,2,4-trichlorobenzene	x	ND	
	chloroform	x	17.8	
	1,2-dichlorobenzene	x	ND	
	ethylbenzene	x	ND	
	naphthalene	x	ND	
	pentachlorophenol	x	ND	
	phenol	x	12	
	bis (2-ethylhexyl) phthalate	x	6.2	
	di-ethylphthalate	x	ND	
	di-methylphthalate	x	ND	
	tetrachloroethylene	x	ND	
	toluene	x	ND	
	trichloroethylene	x	ND	
	di-n-butyl phthalate	-	2.9	
Woven Fabric (Mills A and B)	benzene	x	ND	
	monochlorobenzene	x	ND	
	1,2,4-trichlorobenzene	x	ND	
	2,4,6-trichlorophenol	x	ND	
	p-chloro-m-cresol	x	ND to 290	(B only)
	chloroform	x	ND	
	2-chlorophenol	x	ND	
	1,2-dichloropropane	x	ND	
	ethyl benzene	x	0.8 to 986	
	naphthalene	x	ND to 14.2	
	N-nitrosodiphenylamine	x	ND	
	pentachlorophenol	x	15	(B only)
	phenol	x	ND to 30.4	
	bis(2-ethylhexyl) phthalate	x	4.5 to 19.5	
	di-n-butyl phthalate	x	2.9 to 10.1	
	dimethyl phthalate	x	ND	
	toluene	x	0.3 to 93	
	trichloroethylene	x	ND to 1.1	
	1,1,1-trichloroethane	-	ND to 1.3	
	tetrachloroethylene	-	ND to 86	
	1,4-dichlorobenzene	-	ND to 3.4	

ND - Not detected; Tr - Trace

of five EPA compounds were found with an additional five compounds at concentrations greater than 10 µg/L. At Mill G hosiery operation, three out of the eight EPA compounds were found; there were six additional compounds of greater than 10 µg/L. At Mill G underwear plant, only three out of the thirteen EPA compounds were found. At Mills A and B, eight of the eighteen EPA compounds were found while an additional compound was found at a concentration greater than 10 µg/L.

Table 26 lists the most frequently detected organic priority pollutants by analysis fraction together with the maximum detected concentrations. The most frequently found of all compounds was bis(2-ethylhexyl)phthalate, an ubiquitous plasticizer, which appeared in all 19 samples analyzed. Of the "purgeable fraction" compounds, the substituted benzene compounds were the most frequently detected. In the acid fraction, phenol was most frequently detected. However, the most notable phenol found was pentachlorophenol, which appeared in three of the eighteen samples analyzed. In the base/neutral fraction, the most commonly found polyaromatic hydrocarbon (PAH) was naphthalene, appearing in twelve out of nineteen samples.

Based on results of the 1981/82 toxics screening and the 1985/86 survey as well as reference to the EPA survey, it may be concluded that the following priority pollutants are expected to be found, at the ppb levels, in textile mill effluents:

- substituted benzene, i.e., toluene, ethylbenzene and chlorobenzenes;
- solvents (i.e., chloroform, chloroethanes and chloroethylenes);
- phenols (i.e., phenol and substituted phenol);
- phthalates (i.e., bis(2-ethylhexyl)phthalate and di-n-butylphthalate); and
- naphthalene.

The EPA Effluents Guidelines for textile mills[21], however, propose control only for total phenols and exclude all the other toxic pollutants for two reasons: either they are present in trace amounts too small to be effectively reduced by known technologies, or they are effectively controlled by the technologies on which other effluent limitations and standards are based. The EPA Guidelines set a daily maximum of 0.1 kg/1000 kg of product and a monthly average of 0.05 kg/1000 kg of product for phenols discharged from a textile mill. Total phenols discharged from all the mills surveyed in 1985/86 were found to be well below the limit of 0.05 kg/1000 kg of product.

The frequency detected and the maximum detected concentrations of metal pollutants in effluent discharges found in the 1985/86 survey are summarized in Table 27. The frequencies detected for these pollutants found by the 1979 EPA survey are also

TABLE 26 ORGANIC PRIORITY POLLUTANTS IN CANADIAN TEXTILE MILL WASTEWATERS (1985/86 survey)

Compound	Frequency Detected	Max. Detected Concentration (µg/L)
Purgeables		
toluene	13/17	93
ethylbenzene	13/17	986
1,4-dichlorobenzene	11/17	90.6
chloroform	11/17	448
tetrachloroethylene	11/17	86
1,1,1-trichloroethane	10/17	5.3
trichloroethylene	7/17	44.8
1,1-dichloroethylene	3/17	29.9
1,4-dichlorobenzene	4/17	71.1
1,2-dichlorobenzene	2/17	95
1,2-dichloroethane	1/17	1.5
Acid Fraction		
phenol	12/18	58.6
pentachlorophenol	3/18	19.3
2-nitrophenol	3/18	15
2,4-dichlorophenol	3/18	15
p-chloro-m-cresol	2/18	68.9
2,4-dimethylphenol	2/18	15
Base/Neutral Fraction		
bis (2-ethylhexyl) phthalate	19/19	71
di-n-butyl phthalate	17/19	318
naphthalene	12/19	19.9
fluorene	4/19	2.9

included for comparison. The metals most frequently found in the effluents in the 1985/86 survey were zinc, copper, chromium lead and nickel. In both the Environment Canada and the EPA survey, zinc, copper and chromium were the three most frequently found pollutants. The highest concentrations detected for these pollutants were in the 0.1 mg/L to 0.2 mg/L range. All concentrations found are below the limits of 1 mg/L or 2 mg/L set by the municipal sewer by-law. For Mills A and B, which discharge their treated effluents directly to receiving waters, effluent metal concentrations were within 20 times existing water quality objectives[22]. In most cases and in the case of Mills A

TABLE 27 METAL POLLUTANTS IN TEXTILE EFFLUENTS

Compound	1985/86 Survey*		EPA Survey
	Frequency Detected (greater than 10 µg/L)	Max. Detected Conc. (µg/L)	Frequency Detected (greater than 10 µg/L)
Arsenic	5	14	11/44
Cadmium	3	50	1/44
Chromium	15	230	13/44
Copper	19	145	30/44
Lead	15	100	6/16
Mercury	0	0.95	5/38
Nickel	13	50	9/44
Zinc	20	115	44/44

* based on 21 samples of effluent discharges

and B, the receiving water would provide rapid dilution to over 100 times, indicating that little environmental impact would result from metal pollutants in these discharges.

In the EPA Effluent Guidelines for textile mills (21), chromium was used as a surrogate for the control of all heavy metal pollutants. The discharge limits set for textile mill effluents are 0.1 kg/1000 kg of product and 0.05 kg/1000 kg of product, respectively, for the daily maximum and monthly average. All the mills surveyed in 1985/86 were found to meet the discharge limitations of 0.05 kg/1000 kg of product.

The sources of all major metal pollutants identified (i.e., zinc, copper, chromium, etc.) are likely the dyes used in wet processing. However, potential sources for the organic priority pollutants found in the effluents could be related to their varied uses as briefly discussed in the following:

- those that may be present in commercial dyes or dye carriers as trace impurities or additives are toluene, ethylbenzene, dichlorobenzenes, naphthalene, phenol, nitrophenol, 2,4-dimethylphenol, pentachlorophenol and p-chloro-m-cresol;
- those that may be used as a cleaning solvent or scouring agent are 1,1,1-trichloroethane, trichloroethylene, tetrachloroethylene, chloroform and 1,2-dichloroethane;
- those that may be used as a plasticizer or in coating formulation are bis(2-ethylhexyl)phthalate and di-n-butylphthalate; and
- those that are ubiquitous and may be present in raw water supplies or raw materials are chloroform, 1,2-dichloroethane, phenol and bis(2-ethylhexyl)phthalate.

Conclusions of this subsection regarding priority pollutants in textile effluents are that:

- organic priority pollutants expected to be found in textile effluents, in the ppb level, are substituted benzene (i.e., toluene, ethylbenzene and chlorobenzenes), naphthalene, phenol, substituted phenol (i.e., chlorophenols, methylphenol and nitrophenol), chloroethylenes, chloroethanes, chloroform and phthalates such as bis(2-ethylhexyl) phthalate and di-n-butylphthalate; these pollutants may come as trace or additives in dyes, dye carriers and raw materials as well as from their uses in the wet processing;
- if "total phenols" is used as a surrogate for the control of organic priority pollutants in textile effluents as suggested by the EPA; effluents from the mills surveyed all had a loading of total phenols below 0.05 kg per 1000 kg of product, the limit set by the EPA Textile Mill Effluent Guidelines;
- metal priority pollutants expected to be found in textile effluents are zinc, copper chromium, lead and nickel; the individual concentration of these metals would likely be below 1 mg/L, the discharge limit set by local municipal sewer by-law. The main source of these metal pollutants is the dyes used in the processing; and
- if chromium is used as a surrogate for the control of all heavy metal pollutants in textile effluents as suggested by EPA, effluents from the mills surveyed had a loading of chromium below 0.05 kg per 1000 kg of product, the monthly average limit set by EPA Textile Mill Effluent Guidelines.

4.4 Colour and Effluent Toxicity

The 1981/82 survey included analyses of effluent samples for colour. Both the 1981/82 and the 1985/86 surveys included tests of effluent samples for fish toxicity. The results are summarized in Table 28.

For effluent colour, an absorbance value of less than 0.1 is considered as "not coloured", while a value of between 0.1 and 0.25 is "slightly coloured". Values of greater than 0.25 could be termed as "heavily coloured". Although data for colour absorbance given in Table 28 are rather limited, they do indicate that effluents from mills with secondary treatment may be considered as "not coloured", while effluents from mills with primary treatment are "slightly coloured". Mills with biological treatment plus clarification produced the "least" coloured effluents with a colour absorbance value of only 0.02. However, the discovery of colour plume in rivers near textile mill discharges was reported in various regions [23], indicating that untreated, heavily coloured effluents were occasionally discharged from certain textile mills to rivers.

For effluent fish toxicity, both data from the 1981/82 survey and the 1985/86 survey shown in Table 29 indicate that mills with secondary treatment produced a "non-toxic" effluent with a 96-h LC_{50} of about 100%, while effluents from mills with only

TABLE 28 SUMMARY OF COLOUR AND EFFLUENT TOXICITY DATA

Subcategory		Wastewater Treatment	Colour (absorbance)	Fish Toxicity 96-h LC_{50} (%)
Woven Fabric Finishing				
Mill A	1981/82 Survey 1985/86 Survey	-activated sludge and clarification	0.02	100 100
Mill B	1981/82 Survey 1985/86 Survey	-aerated lagoon	0.08	80 ± 16 99
Knit Fabric Finishing				
Mill C	1981/82 Survey	-chemical coagulation, aeration lagoon and clarification	0.02	100
*Mill G	Underwear 1985/86 Survey Hosiery 1985/86 Survey	-equalization		75 42
Wool Finishing				
*Mill F	1981/82 Survey 1985/86 Survey	-screening and equalization	0.24	14 ± 4 72
Carpet Finishing				
*Mill D	1981/82 Survey	-screening	0.2	6.9 ± 1.0
*Mill E	1981/82 Survey 1985/86 Survey	-screening	0.2	8.8 ± 0.4 70

* discharged to municipal sewer

screening were somewhat toxic to fish, with a LC_{50} value of from 7% to 14% (1981/82 data) and 42% to 75% (1985/86 data). Both Mill E and Mill F show a great improvement in effluent fish toxicity from 1981/82 to 1985/86 (i.e., from 14% to 72% and from 8.8% to 70%, respectively). The 1985/86 survey, however, used guppy fry as the test species, while the 1981/82 survey used rainbow trout; guppy fry are about 1.5-fold more tolerant than rainbow trout[20].

It may be concluded that textile mills with a well-operated biological treatment system could produce an effluent non-lethal to fish and with no apparent colour

TABLE 29 SUMMARY OF SURFACTANT CONCENTRATIONS IN EFFLUENTS

Subcategory			Anionic Surfactants as MBAS (mg/L)	Non-ionic Surfactants (mg/L)	Wastewater Treatment
Woven Fabric Finishing					
Mill A	1981/82	Raw wastewater	2.3	1350	- activated sludge plus clarification
		Final effluent	0.9	500	
	1985/86	Raw wastewater	-	6.1	
		Final effluent	-	3.1	
Mill B	1981/82	Raw wastewater	3.9	1800	- aerated lagoon
		Final effluent	1.7	1430	
	1985/86	Raw wastewater	-	6.5	
		Final effluent	-	3.2	
Knit Fabric Finishing					
Mill B	1981/82	Raw wastewater	2.7	340	- chemical coagulation, aerated lagoon and clarification
		Final effluent	0.6	30	
*Mill G	Hosiery		-	24	- equalization
	1985/86	Final effluent			
*Mill G	Underwear		-	15	- none
	1985/86	Final effluent			
Wool Finishing					
*Mill F	1981/82	Final effluent	2.7	1210	- screening and equalization
	1985/86	Final effluent	-	88	
Carpet Finishing					
*Mill D	1981/82	Stream 1	2.9	1290	- screening
	1981/82	Stream 2	1.4	480	
*Mill E	1981/82	Main effluent	16.5	380	- screening
		Latex effluent	1.3	-	
	1985/86	Main effluent	-	101	
		Latex effluent	-	0.2	

* discharged to municipal sewer

and effluents from mills with only primary treatment would be slightly coloured and have a fish toxicity of less than 70% 96-h LC_{50}.

4.4 Surfactants

Textile wet processing uses a large quantity of surfactants as agents and/or auxiliary agents for scouring, wetting, dispersing, dyeing and finishing. Most of the surfactants used, after serving their purpose, end up in the wastewater. The 1981/82 survey included analyses of effluent samples for anionic surfactants and non-ionic surfactants; the 1985/86 survey included only analyses for non-ionic surfactants. Results of these analyses are summarized in Table 29.

For anionic surfactants, analyzed as Methylene Blue-Active Substances (MBAS), the concentration in wastewaters varied from 1.4 to 16.5 mg/L depending on the processes employed, the chemicals used as well as the water use. The MBAS values are not the true concentration of anionic surfactants; however, they give an indication of the anionic surfactant level in wastewaters. Data for Mills A and C show that the existing treatment in these two mills reduced the anionic surfactant concentration by 60% and 80%, respectively. Mill C, which had chemical coagulation prior to the biological treatment and clarification after the biological treatment, produced an effluent containing a rather insignificant amount of anionic surfactants with a MBAS value of only 0.6 mg/L. For Mill B, a 54% reduction of anionic surfactants by the treatment system was observed. The 5-day retention time in the lagoon, however, probably precluded a calculation of the true percentage reduction.

For non-ionic surfactants, data from Mill C indicate a reduction of over 90%. However, data for Mill A show a reduction of only 60% (1981/82 survey) and 50% (1985/86 survey). The biodegradation of surfactants is known to depend on the temperature. The differences in the % reduction obtained may be caused by a difference in the temperature involved.

In conjunction with the 1985/86 survey, non-ionic surfactant concentrations in the influent and effluent of a municipal sewer treatment plant (STP) were studied[20]. The municipal STP, a secondary treatment plant, received approximately 15% of its total flow and about 90% of its non-ionic surfactant loading from Mill F discharges. The mean concentrations of the STP influent and effluent (which had a temperature close to 20°C at the time of the study) for non-ionic surfactants were found to be 15 mg/L and 0.8 mg/L, respectively, achieving a reduction of 96.5%. This confirms that good removal of non-ionic surfactants can be achieved with biological treatment. In addition, it was found that

surfactants from Mill F did not cause significant foaming problems in this particular municipal STP.

A surprising finding in Table 29 is the order-of-magnitude differences in concentrations of non-ionic surfactants between the 1981/82 and the 1985/86 surveys. While at Mill E the four-fold decrease may be attributed to the decrease in chemical consumption by the mill, the decreases found in Mills A, B and F are too large to be caused only by a reduction in chemical usage. It should be noted that different procedures were used in the two surveys; the 1981/82 survey used the dichlorofluoroscein decolourization method[24], while the 1985/86 survey used the CATS (Cobalt Thiacyanate Active Substances) method[25]. A comparison of the calculated annual loading with the estimated annual consumption provided by Mills A and F for the 1985/86 survey (Table 30) indicates that analytical results of the 1985/86 survey are reasonably accurate. Analytical results of the 1981/82 survey appear to be significantly higher than the actual concentrations as can be seen from the fact that effluents with non-ionic surfactant concentrations of over 500 mg/L were not toxic to fish (Tables 28 and 29), yet it is known[20] that most of the non-ionic surfactants have a 96-h LC_{50} of less than 10 mg/L.

TABLE 30 COMPARISON OF UNTREATED WASTEWATER DISCHARGES OF NON-IONIC SURFACTANTS TO ESTIMATED PLANT USE (1985/86 survey)

	Flow (m^3/day)	Non-Ionic Surfactant Concentration (mg/L)	Non-Ionic Surfactant Loading (kg/day)	Calculated Annual Discharge (kg/yr)	Estimated Annual Plant Use (kg/yr)
Mill A	9215	6.1	56.2	14 050	20 000
Mill F	1054	88	92.8	23 200	39 200

Observations regarding surfactants in textile effluents are that: a well-operated biological treatment system could reduce the surfactants to an insignificant level; and municipal STP receiving discharges from textile mills with only primary treatment experienced no foaming problems.

4.5 Sludges and Other Wastes

The 1985/86 survey included the collection of available information on sludges and wastes other than wastewaters.

Among the mills surveyed, most did not produce or did not regularly produce any sludges. Only Mill A reported the production of 200 m^3/week of wastewater treatment sludges which were wasted to a river and Mill E reported 27 m^3/month of sludges from its latex settling tank which went to a landfill site. Mill F produced an insignificant amount of sludges once every two years from its equalization tank; the sludges were hauled off-site by a contractor. All other mills surveyed, including Mill B which has a 5-day retention aerated lagoon, produced no sludge for disposal.

Two samples of return sludge from the Mill A wastewater treatment system as well as bottom sludge samples from the Mill B aerated lagoon were collected and analyzed for contaminants. However, only samples from Mill B were successfully analyzed. According to a study by Shaver and Guinan[26], the total heavy metal concentration in wastewater treatment sludges from U.S. textile mills may reach 20 990 ppm and the concentration of chlorinated hydrocarbons in these sludges ranges from 0.11 ppm to 64.7 ppm (Table 31). For Mill B, a woven fabric dyeing and finishing mill, the total metal concentrations in sludges near the lagoon influent and effluent were about 2000 ppm and 1550 ppm, respectively. These values are much lower than the value of 9395 ppm given in Table 31 for woven dyeing and finishing mills in the U.S. The total concentrations of chlorinated hydrocarbons for sludges from Mill B (i.e., 0.65 ppm and 0.19 ppm) are also much lower than the value of 15.2 ppm given in Table 31 for woven fabric dyeing and finishing mills.

Other wastes reported by the mills surveyed included waste fabrics, screened or settled fibres, filtered fibre dust and stock (from wool finishing mills); these were all sent to a municipal landfill site for disposal. Two mills reported some waste oil from skimming of oil mist scrubbers; one disposed of it by incineration on-site the other by a hauler to off-site disposal. One mill also reported some 12 000 kg/yr of waste PVA foam which was disposed off-site by landfill.

Most of the mills did not produce sludges on a regular basis; insignificant amounts of sludges were generated occasionally from tank bottoms and were disposed of by landfill. Wastewater treatment sludges contained heavy metals and chlorinated hydrocarbons. However, concentrations found in the samples analyzed were much lower than those reported for the same type of U.S. mills. Other wastes produced include waste fabrics and fibres which are usually disposed in municipal landfill sites. Some mills may produce waste oils which have to be safely disposed of.

TABLE 31 SUMMARY OF U.S. TEXTILE MILL SLUDGE ANALYSES

Category	Total Heavy Metals mg/kg of dry sludge	Total Chlorinated Organics mg/kg of dry sludge
Wool Scouring	5 273	1.28
Wool Fabric Dyeing and Finishing	20 990	0.11
Woven Fabric Dyeing and Finishing	9 395	15.2
Knit Fabric Dyeing and Finishing	5 023	64.7
Carpet Dyeing and Finishing	7 919	26.2
Yarn and Stock Dyeing and Finishing	3 606	40.1

4.6 Air Emissions

The 1985/86 survey questionnaire included a section on air emissions, however, very little information was collected on sources, contaminants and control of air emissions.

Most mills surveyed had particulate emissions and fibre dust which were controlled by bagfilters, cyclone or central suction. Some mills reported emissions of solvent vapours (e.g., trichloroethylene and perchloroethylene), with no information on control. A few mills reported emissions of oil mists and used scrubbers to collect the oil. A wool finishing mill reported some emissions of ammonia, a woven fabric finishing mill reported water vapour containing certain resins, and a knit fabric finishing mill reported the emissions of sodium hypochlorite and sodium hydrosulphate vapours.

It appears that the major air pollution problem of textile mills is the emission of fibre dust. According to a U.S. study[13], however, textile processing may contribute significantly to volatile organic compound (VOC) concentrations in the atmosphere. Fabric printing has the most potential for high VOC emissions depending on the print paste solvent content. Nevertheless, from the limited information/data obtained through the returned questionnaires and plant visits, the problem of VOC emission from Canadian textile mills seems to be not as serious as what has been described in the literature. Perhaps, the significance of air emissions from Canadian textile mills should be determined through a survey specially designed for such a purpose.

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APPENDIX A
THE 1978 PROPOSED EFFLUENT GUIDELINES FOR TEXTILE MILLS

The proposed guidelines:

- apply to all existing textile mills;
- limit the discharge of BOD and TSS and specify the pH of the effluent discharged as well as the acute lethality;
- the allowable BOD discharge is expressed in kilograms of pollutants per 1000 kilograms of fibre processed in a given component process (see Table A-1);
- the arithmetic mean of the actual daily deposit of TSS on any four operating days within a normal mill accounting period does not exceed 8 kg/1000 kg of average daily mill production, plus 4.5 kg/1000 kg of raw wool degreased during those four days;
- the pH of each grab sample or combined grab sample of effluent determined in accordance with subsection 3(3) is between 6.0 and 9.0; and
- the acute lethality requirements is 50% survival in the bioassay sample when tested according to the procedure specified.

TABLE A-1 MAXIMUM DEPOSITS OF BOD

Process	Wool Fibre or Fabric Allowance	Cotton Fibre or Fabric Allowance	Man-made Fibre or Fabric Allowance	Remarks
1. Raw wool degreasing	35.0	-	-	
2. Sizing and/or jet loom weaving	0.2	0.2	0.2	Subject to Condition 1
3. Pretreatment	-	-	5.0	Subject to Condition 2
4. Desizing	10.0	10.0	-	
5. Scouring	7.5	7.5	-	
6. Bleaching	0.4	1.0	-	
7. Mercerizing	-	1.0	-	
8. Fulling	5.0	-	-	
9. Dyeing	4.0	4.0	4.0	
10. Dyeing with Dyecarrier	-	-	8.0	
11. Printing	4.0	4.0	4.0	
12. Printing of Carpets	-	-	15.0	
13. Finishing	0.3	0.3	0.3	

Note: All values are expressed in kilograms of BOD per thousand kilograms of commercial dry fibre processed.

Condition

1. This allowance does not apply to fibre that is sized and desized at the same mill.
2. For man-made fibres an allowance for pretreatment is permitted for all fibre that is dyed or printed even if the pretreatment step does not exist as a discrete process stage.

APPENDIX B
DETAILED SAMPLING AND ANALYTICAL PROCEDURES OF THE 1985/86 SURVEY

B.1 Sampling Procedures

Sampling for all chemical parameters except the volatile organics was performed using automatic composite samplers. Both Sigma and Isco peristaltic pump type samplers were used. To minimize the potential for contamination from the medical grade silicone rubber tubing used in the pump head, lengths of silicone tubing were restricted to 30 cm. The balance of sampler intake and discharge tubing was 1.2 cm ID heavy wall teflon tubing. Sampler containers were 20 L pyrex glass narrow-necked carboys cleaned with an organic detergent, rinsed three times with distilled water and again twice with distilled-in-glass acetone. The mouths of the carboys were covered with skived teflon film to prevent contamination before, during and after use.

The volatile organics samples were grab samples collected in 250- or 125-mL amber glass bottles at the end of each 24-hour composite. Consequently, they are representative of the instant in time at which they were collected. Each bottle was filled to overflowing and capped with a teflon-faced silicon rubber septum and screw cap to exclude any air bubbles.

B.2 Analytical Procedures

The preservation and analytical procedures used for all wastewater samples and analytical parameters are summarized in Table B-1. Sludges were refrigerated in glass jars with teflon lined caps until analyzed.

To overcome the problem of emulsion during extraction, the laboratory (Mann Testing) used a continuous liquid-liquid extraction system designed for solvents heavier than water. This system operates in a manner similar to a Soxhlet extraction by distilling solvent from a collection reservoir into a condenser from which it drips into a vessel containing the sample. The heavier than water solvent falls through the aqueous sample creating a layer of solvent at the bottom of the sample vessel which underflows by gravity back to the solvent reservoir. Extraction usually required 24 hours to complete. A schematic of the apparatus is shown in Figure B-1.

Two features of the GC/MS analysis process should be highlighted. Interference from surfactants and dyes occurred in both the acid fraction extracts and the base/neutral fraction extracts. In the case of the acid fraction (phenols) the interferences could not be removed; therefore, dilute extracts had to be used rather than concentrated extracts. Consequently, the method detection limits were degraded from the usual 3 to

TABLE B-1 PRESERVATION AND ANALYSIS PROCEDURES

Parameter	Preservation		Analytical Method
Nonionic Surfactants	4°C		Cobalt Thiocyanate Active Substances
BOD	4°C		APHA Standard Methods (15th Ed.)
COD	H_2SO_4,	pH = 2	APHA Standard Methods (15th Ed.)
pH	4°C		radiometer pH meter
TSS/TDS	4°C		APHA Standard Methods (15th Ed.)
Total Phenolics	H_3PO_4, plus $CuSO_4$	pH = 4	4-Amino-antipyrine, APHA Standard Methods (15th Ed.)
NH_3-N	H_2SO_4,	pH = 2	Micro Kjeldahl, APHA Standard Methods (15th Ed.)
Metals	HNO_3,	pH = 2	HNO_3 digestion, Beckman DCP
Mercury	HNO_3,	pH = 2	HNO_3 digestion, cold vapour AA
Arsenic	HNO_3,	pH = 2	HNO_3 digestion, hydride generation AA
EPA Volatile Organics	4°C, max. 7 days		EPA Method 624
EPA Acid Fraction (Phenols)	4°C		EPA Method 625
EPA Base/Neutrals Organics	4°C		EPA Method 625

5 µg/L by approximately five-fold to 15 to 25 µg/L. In the case of the base/neutrals, a florosil cleanup was successfully applied to remove dye interferences. Recoveries of the priority organic pollutants were monitored through the use of deuterated analogues, and were found to be excellent. Detailed analytical procedures are:

B.2.1 Volatile.

a) Sampling Preparation - Collection and Handling

Water samples for purgeable organics were collected in 50-mL capacity amber glass bottles equipped with Tuf-Bond discs and screw caps with a syringe access hole in

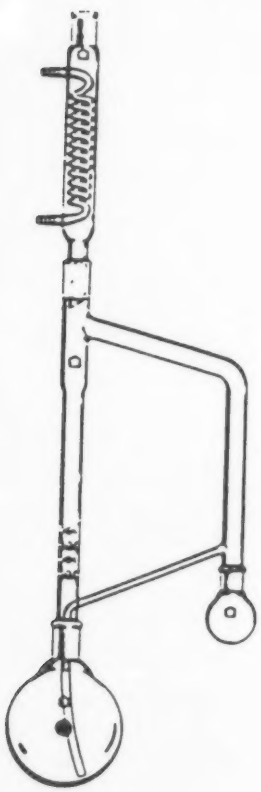

FIGURE B-1 K-584100 CONTINUOUS EXTRACTION APPARATUS

the centre. The bottles had been previously cleaned and heated at 200°C for at least four hours, purged with nitrogen and sealed with PTFE-coated silicone and open top caps prior to transportation to the sampling sites.

The bottles were filled to slight overflow, then sealed so that no air bubble was present in the sample. They were immediately returned to Mann Testing Labs and stored at 4°C until analyzed.

b) Preparation of Standard Solutions

Stock standard solutions were prepared by injecting appropriate amounts of each pollutant into 25 mL of glass-distilled methanol in reactiflasks fitted with Minnert valves which provide complete protection and easy access via a hypodermic needle. The resulting concentration of 1 mg/mL was further diluted to give methanolic solutions of 400 µg/mL, 40 µg/mL and 4 µg/mL for each component. Gaseous standards were prepared in a similar manner by injecting the gaseous compound from a 10-mL gas-tight syringe into a pre-weighed reactiflask filled with 25 mL of methanol. The syringe needle was slightly above the ethanol meniscus while injecting, enabling the gas to dissolve rapidly into the methanol. The flask was re-weighed to determine the amount in the solution.

Aqueous composite standards were prepared by injecting appropriate aliquots of methanolic standard in 250-mL sample bottles filled with purified water.

The relative retention times (RRT) were compared to that of the internal standard, deuterated chlorobenzene (RRT = 1.00) which eluted close to the middle of the chromatogram. Detection limits were determined by purging aqueous composite standard mixture at various concentrations.

c) Instrumentation

Analysis of volatile organics in water was conducted using a UNACON 780B automatic concentrator. This instrument is used for the isolation and concentration of volatiles for chromatographic analysis. In general, this process involved gas stripping of the sample and adsorption of the organic compounds on a sorbent trap followed by thermal desorption and analysis by gas chromatography or gas chromatography/mass spectrometry.

The sample purging assembly included a sparger vial with a side port which was equipped with an open top screw cap and Tuf-Bond septum. A 30-mL vial was used to obtain detection limits as reported. Sample was transferred to the vial through a transfer line by pressurizing the sample bottle which was inverted and clamped on the side of the instrument. The transfer line was constructed of 1/16" (1.6 mm) teflon tubing with two Luer Lock connectors at each end. Two 17-gauge needles were used to puncture the septa of both the bottle and the side port.

Prior to the start of the analysis, the sparger vial was purged with helium for five minutes by rotating the valve to "Trap-Out" mode. In this position, any contaminants that were present in the sparger vial were purged out of the system without entering the trap. An appropriate aliquot of the water was then transferred to the sparger and purged for 15 minutes at the "Trap-In" mode. The trap was head desorbed and the organics backflushed into the second trap. When this transfer process was completed, the second trap was again heated, releasing all adsorbed organics into the capillary GC/MS system for identification and quantification.

The MDL (Method Detection Limit) listed in the volatile section is the limit that the compound can be identified and quantified in the sample matrix using the purge and trap GC/MS method.

d) QA/QC

Prior to sample analysis reference standards were analyzed to determine the instrument response for standards of known levels. Instrument blanks were then analyzed to determine the extent of any instrument contamination. Travelling blanks for each set of samples were analyzed to measure any possible background contamination caused by the sample container. At ten sample intervals duplicate samples were analyzed to monitor the analytical reproducibility.

B.2.2 Extractable.

a) Standard Compound Characterization

A Standard solution containing approximately 1.0 ng/μL of each of the selected priority pollutants was prepared and analysed by GC/MS to determine each compound's fragmentation pattern, relative retention time (RRT) and relative response factor (RRF) compared to the internal standard D_{10} Phenanthrene. A 10 ppb dilution of this standard was routinely run prior to sample analysis to insure

optimum performance of the GC/MS system. The minimum detection limit (MDL) represents the minimum level at which a compound can be detected and quantitated. Values were determined by comparison of the response of the labelled internal standards to the level of background interference in the region of the corresponding natural compound. These values are averages obtained from actual sample matrices.

b) Target Compound % Recovery

The % recovery of individual target compounds was determined by spiking 1 L of purified distilled water at the 20 ppb level with a standard mixture containing all of the compounds of interest. Recovery values and the method detection limit (MDL) are listed in Table B-2.

TABLE B-2 EPA PRIORITY ORGANIC POLLUTANTS MINIMUM DETECTION LIMITS AND PERCENT RECOVERIES (1 L water/20 ppb)

Acidic Compounds	MWT	Quant. Ion	RRT	MDL	% REC
Phenol	94	94	0.270	15	25.0
2-Chlorophenol	142	142	0.390	10	40.6
2,4-Dimethyl phenol	136	107	0.431	15	24.5
p-Chloro-m-cresol	156	156	0.485	25	83.4
2,4-Dichlorophenol	176	176	0.559	15	47.9
2,4,6-Trichlorophenol	210	195	0.609	10	70.3
2-Nitrophenol	153	153	0.609	15	29.6
2,4-Dinitrophenol	198	91	0.772	15	16.5
4,6-Dinitro-o-cresol	212	265	0.921	25	77.5
Pentachlorophenol	280	280	0.962	25	80.9
4-Nitrophenol	153	153	0.652	15	27.0

c) Sample Extractions

To monitor the extraction efficiency of individual sample extractions. Each sample was spiked at the 20 ppb level with a mixture of 11 deuterated acid extractables and 19 deuterated B/N compounds.

To monitor injection efficiency all extracts were spiked with 20 ppb of D-10 Phenanthrene immediately prior to GC/MS analysis.

d) QA/QC Protocol

i) The use of a stock mixture of deuterated internal standards (Table B-3) to monitor extraction efficiency assures a high confidence level in the results in all sample extractions.

ii) Travelling blanks were analyzed at ten sample intervals to insure that outside contamination was not interfering with the observed results.

iii) Prior to sample analysis, reference standards at the 10 ppb level were analyzed to demonstrate that the instrument was capable of the required sensitivity. Solvent blanks were run between standards and samples to monitor any possible cross contamination. Reference standards at various levels were analysed after every tenth sample.

TABLE B-3 ISOTOPICALLY LABELLED INTERNAL STANDARDS

Compound	Natural Quant. Ion	Deuterated Quant. Ion
Acid Extractable		
4-Chloro-3-methylphenol, 2.6-d_2	142	144
2-Chlorophenol-3,4,5,6-d_4	128	132
2,4-Dichlorophenol-3,5,6-d_3	162	164
2,4-Dimethylphenol-3,5,6-d_3	122	125
4,6-Dinitro-2-methylphenol-3,5-d_2	198	200
2,4-Dinitrophenol-3,5,6-d_3	184	187
2-Nitrophenol-3,4,5,6-d_4	139	143
4-Nitrophenol-2,3,5,6-d_4	139	143
Pentachlorophenol-$^{13}C_6$	266	272
Phenol-2,3,4,5,6-d_5	94	99
2,4,6-Trichlorophenol-3,5-d_2	196	198
Base/Neutrals		
Benz(a)anthracene-d_{12}	228	240
Benzyl n-Butyl Phthalate-3,4,5,6-d_4	149	153
Bis (2-chloroethoxy)-d_8-methane	93	101
Bis (2-ethylhexyl) Phthalate-3,4,5,6-d_4	149	153
Dibenzo(a,h)anthracene-d_{14}	278	292
1,2-Dichlorobenzene-d_4	146	153
1,4-Dichlorobenzene-d_4	146	153
Dimethyl Phthalate-3,4,5,6-d_4	163	167
2,6-Dinitrotoluene-a,a,a-d_3	165	168
Nitrobenzene-d_5	123	128
1,2,3-Trichlorobenzene-4,5,6-d_3	180	183
Acenaphthene-d_{10}	154	164
Anthracene-d_{10}	178	188
Benzo (k) fluoranthene-d_{12}	252	264
Bis (2-chloroethyl)-d_8 Ether	93	101
Chrysene-d_{12}	228	240
Fluorene-d_{10}	166	176
Naphthalene-d_8	128	136
Pyrene-d_{10}	202	212

e) Target Compound Identification and Quantitation

The GC/MS data files were searched for the selected pollutants using a computer program that searched successive regions of the chromatogram plotting out ion intensities of the two most abundant ions of both the target compound and labelled standards eluting in that region. The identity of detected compounds was verified by manual confirmation (mass spectra matching).

Quantitation of target compounds was achieved by comparing the peak heights of the neutral compound to that of its analogous labelled standard which had been spiked into the sample at a known level. For those target compounds whose corresponding labelled standards were not available, the labelled standard that eluted closest to it was used for quantitation.

f) Extraction Procedure

i) A 1-L volume of sample water was spiked at the 20 ppb level with a mixture of deuterated standards (the sample was shaken and allowed to equilibrate for one hour at room temperature.

ii) The pH was adjusted to a pH=11 using 6N NaOH and the sample continuously extracted using a heavier than water continuous extractor (Figure B-2).

iii) The pH was then changed to pH2 using 6N HCl and extracted for an additional 24 hours to extract the acidic and phenolic compounds.

iv) The CH_2Cl_2 fraction was extracted with 3 x 50 mL of 0.1N NaOH, then dried through Na_2SO_4 (base/neutral fraction). The aqueous portions were combined and acidified then re-extracted with 3 x 50 mL of CH_2Cl_2 which was dried using Na_2SO_4 (phenolic fraction).

v) The dried extracts were collected in 1L Kuderna-Danish evaporators containing 2 mL of isooctane then concentrated to a volume of approximately 10 mL.

vi) Florisil cleanup - Base/Neutral fraction - a 1-mL aliquot of the 10-mL extract was applied to a small florisil cleanup column and eluted with 10 mL of dichloromethane.

vii) The extract was concentrated to 1 mL using nitrogen and analyzed by GC/MS.

viii) The phenolic fraction was derivatized with diazomethane (3% in ether) and concentrated to 5 mL. GC/MS analysis was performed directly on the 5-mL extract.

ix) Gas Chromatographic/Mass Spectrometry Instrumentation

One-µL mliquots of the 1-mL extracts were analysed for the presence of the selected priority pollutants using a Finnigan 4500 GC/MS system set to the following condition:

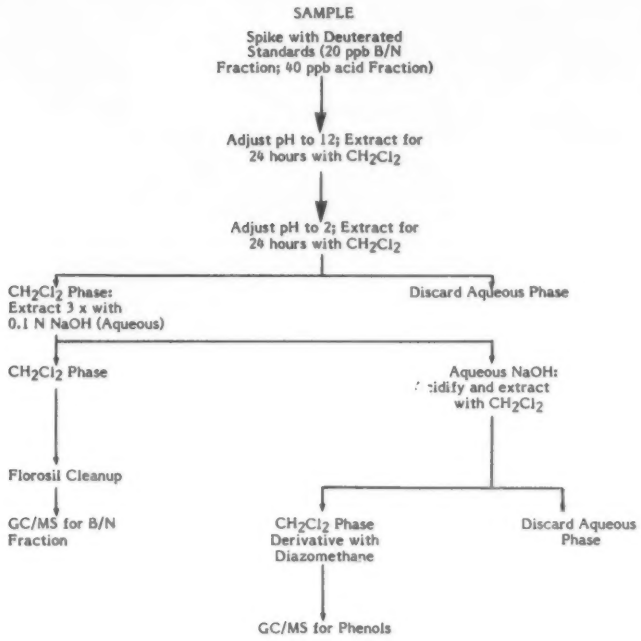
SAMPLE
Spike with Deuterated Standards (20 ppb B/N Fraction; 40 ppb acid Fraction)
Adjust pH to 12; Extract for 24 hours with CH_2Cl_2
Adjust pH to 2; Extract for 24 hours with CH_2Cl_2
CH_2Cl_2 Phase: Extract 3 x with 0.1 N NaOH (Aqueous)
Discard Aqueous Phase
CH_2Cl_2 Phase
Aqueous NaOH: Acidify and extract with CH_2Cl_2
Florosil Cleanup
GC/MS for B/N Fraction
CH_2Cl_2 Phase Derivative with Diazomethane
Discard Aqueous Phase
GC/MS for Phenols

FIGURE B-2 EXTRACTION PROCEDURE

All injections were performed using an on column technique.

MASS SPECTROMETER

Electron Multiplier	-	1450 eV
Ionization Energy	-	70 eV
Sensitivity	-	10^8 amps/volt
Scan Rate	-	2.25 ms/mass unit
Scan Range	-	1 to 2000
Mass Range	-	60 to 450 atomic mass unit

Finnigan Gas Chromatograph Conditions

Instrument	-	Varien 3500
GC Column	-	DB-5 30 M capillary
GC Temp. Program		
Initial	-	50°C (0.1 min.)
Final	-	2850°C (20 min.)
Rate	-	10°C/min.
Injection Port Temp.	-	250°C
Column Carrier Gas	-	Helium

B.3 Effluent Toxicity

Toxicity tests were 96-h static acute toxicity bioassays performed using the principles outlined in: Standard Procedures for Testing the Acute Lethality of Liquid Effluents, Environment Canada (EPS-WP-80-1), and the standard method ISO 7346/1 for measuring lethality to fish. Acute lethality for each effluent was established by determining the 96-h median lethal concentration (LC_{50}) (the concentration of effluent sample that is lethal to 50% of the fish exposed to that concentration for 96 hours).

Juvenile common guppies (*Lebistes reticulatus*) (mean length 38±1.76 mm) were used in the bioassays. Guppies were selected because of limited volumes of sample, and their size permitted appropriate loading rates. The main stock was obtained from a healthy stock at Hartz Canada in Toronto. The fish were acclimated in BEAK's Mississauga laboratory in a holding tank (water temperature 22±1°C) for two months before testing. Before tests were performed each time, gravid females selected from the stock culture were isolated in breeding chambers and newborn fish were collected 24 or 48 hours later for testing. Different adults provided fish fry for definitive tests. Rainbow trout used in comparative bioassays were obtained from a healthy stock at Aquafarms, Feversham, Ontario. The fish were acclimated in BEAK's Mississauga laboratory in a holding tank (water temperature 15°C) for 14 days before testing. Holding and dilution water quality is presented in Table B-4.

TABLE B-4 DILUTION WATER CHARACTERISTICS (dechlorinated Mississauga tap water)

Chemical Parameter		mg/L
pH		7.4
Alkalinity		97
Hardness (as $CaCO_3$)		143
Conductivity (µS/cm)		327
Ammonia-N		0.06
Chlorine (total residual)		0.05
COD		1.3 to 7.8
DOC		0.5 to 3.0
TOC		0.5 to 3.0
Anion Scan	- Bromide	
	Chloride	0.05
	Fluoride	33
	Nitrate-N	1.3
	Nitrite-N	0.50
	O-Phosphate-P	0.1
		0.1
DCP Scan	- Aluminum	
	Berylium	0.06
	Barium	0.005
	Cadmium	0.025
	Calcium	0.005
	Chromium	43
	Cobalt	0.005
	Copper	0.01
	Iron	0.005
	Lead	0.01
	Manganese	0.03
	Magnesium	0.01
	Nickel	9.7
	Potassium	0.01
	Silver	1.9
	Strontium	0.01
	Sodium	0.20
	Vanadium	16.1
	Zinc	0.005
		0.010

Toxicity tests incorporated a logarithmic series of effluent and toxicant concentrations to each of which 10 fish were exposed for 96 hours. The test solutions were aerated to maintain the concentration of dissolved oxygen above 8 mg/L. A fish loading rate of 0.5 L test solution/g of fish/day was maintained throughout the exposure period. The bioassays were conducted in 500-mL glass containers, each containing 200 mL of test solution held at a constant temperature of 22±1°C. A photoperiod of 12 hours light/12 hours darkness was maintained during testing. The tests were accompanied by a control in which the fish were exposed to dechlorinated Mississauga tap water under the same test conditions. The specific conditions of the bioassays are presented in Table B-5. Dissolved oxygen, pH, temperature and fish survival were monitored daily in each test container.

TABLE B-5 CONDITIONS OF ACUTE LETHALITY BIOASSAYS

Test Type:	Static
Test Temperature:	22±1, °C
Test Volume:	200 mL
Photoperiod:	12 hours light/12 hours dark
Test Organism:	common guppy (*Lebistes reticulatus*)
Stock Source:	Hartz Canada Ltd., Ontario
Stock Number:	C6-1-85
Stock Acclimation Period (days):	60
Fish Lengths (range) (mm):	15 to 23
Fish Weights (range) (g):	0.045 to 0.075
Loading Rates (L/g/d):	0.5
Reference Toxicant Sensitivity	
Sodium Pentachlorophenate	
LC_{50} (mg/L)	0.31
95% Confidence Interval	0.23 to 0.44
Rexol 25/7	
LC_{50} (mg/L)	13
95% Confidence Interval	10 to 16
Rexonic N91-6	
LC_{50} (mg/L)	15
95% Confidence Interval	1 to 20

APPENDIX C
ANALYTICAL RESULTS

TABLE C-1 ANALYTICAL RESULTS FOR MILL A (1981/82 toxics screening)

Sample/Fraction	EPS Atlantic Lab.	WTC Lab.	KER Lab
Sample No. 01 (Raw Water)			
Acid Fraction	all parameters <20 ppb	NA	NA
Neutral Fraction	all parameters <20 ppb	NA	NA
Sample No. 03 (Dye House Effluent)			
Acid Fraction			
4-chloro-3-methylphenol	32 ppb	14 ppb	38 ppb
phenol	28 ppb	<25 ppb	42 ppb
Neutral Fraction			
naphthalene	12 ppb	10 ppb	<2 ppb
di-n-butylphthalate	NA	10 ppb	<2 ppb
bis(2-ethylhexyl)phthalate	NA	60 ppb	246 ppb
Sample No. 04 (Primary Effluent)			
Acid Fraction			
pentachlorophenol	NA	all parameters <25 ppb	70 ppb
Neutral Fraction		<25 ppb	
naphthalene	21 ppb	16 ppb	29 ppb
di-n-butylphthalate	NA	8 ppb	<2 ppb
bis(2-ethylhexyl)phthalate	NA	56 ppb	408 ppb
n-nitrosodiphenylamine	NA	<10 ppb	16 ppb
Sample No. 05 (Final Effluent)			
Acid Fraction	all parameters <20 ppb	NA	NA
Neutral Fraction	all parameters <20 ppb	NA	NA

NA - not analyzed

TABLE C-2 ANALYTICAL RESULTS FOR MILL B (1981/82 toxics screening)

Sample/Fraction	EPS Atlantic Lab.	WTC Lab.	KER Lab.
Sample No. 6 (Raw Water)			
Acid Fraction	all parameters <20 ppb	NA	NA
Neutral Fraction	all parameters <20 ppb	NA	NA
Sample No. 7 (Mill Effluent)			
Acid Fraction	all parameters <20 ppb	NA	NA
Sample No. 08 (Final Effluent)			
Acid Fraction	all parameters <20 ppb	NA	NA
Neutral Fraction	all parameters <20 ppb	NA	NA

NA - not analyzed

TABLE C-3 ANALYTICAL RESULTS FOR MILL C (1981/82 toxics screening)

Sample/Fraction	EPS Atlantic Lab.	WTC Lab.	KER Lab.
Sample No. 6 (Raw Water)			
Acid Fraction	all parameters <20 ppb	NA	NA
Neutral Fraction			
1,2,4 trichlorobenzene	15 ppb	24 ppb	
naphthalene	17 ppb	12 ppb	
1-methylnaphthalene	NA	94 ppb	
di-n-butylphthalate	NA	58 ppb	
bis (2-ethylhexyl)phthalate	NA	83 ppb	
Sample No. 2 (Primary Effluent)			
Acid Fraction	all parameters <20 ppb	NA	NA
Neutral Fraction	all parameters <20 ppb	NA	NA
Sample No. 3 (Final Effluent)			
Acid Fraction	all parameters <20 ppb	NA	NA
Neutral Fraction	all parameters <20 ppb	NA	NA
Sample No. 4 (Raw Water)			
Acid Fraction	all parameters <20 ppb	NA	NA
Neutral Fraction	all parameters <20 ppb	NA	NA

NA - not analyzed

TABLE C-4 ANALYTICAL RESULTS FOR MILL D (1981/82 toxic screening)

Sample/Fraction	EPS Atlantic Lab.	WTC Lab.	KER Lab.
Sample No. 30 (Raw Water)			
Acid Fraction	all parameters <20 ppb	NA	NA
Neutral Fraction	all parameters <20 ppb	NA	NA
Sample No. 31 (Dye Waste)			
Acid Fraction		all parameters <25 ppb	
4-nitrophenol	NA	<25 ppb	116 ppb
phenol	<20 ppb	<25 ppb	20 ppb
Neutral Fraction			NA
1,2,4 trichlorobenzene	21 ppb	32 ppb	
naphthalene	139 ppb	132 ppb	
fluorene	NA	22 ppb	
1-methylnaphthalene	NA	8 ppb	
2-methylnaphthalene	NA	16 ppb	
bis(2-ethylhexyl)phthalate	NA	64 ppb	
Sample No. 32 (Latex Waste)			
Acid Fraction	sample lost	-	-
Neutral Fraction	<20 ppb		

NA - not analyzed

TABLE C-5 ANALYTICAL RESULTS FOR MILL E (1981/82 toxics screening)

Sample/Fraction	EPS Atlantic Lab.	WTC Lab.	KER Lab.
Sample No. 8 (Rotary Printer Effluent)			
Acid Fraction	-	all parameters <25 ppb	NA
Neutral Fraction	all parameters <20 ppb	NA	NA
Sample No. 9 (Continuous Dyer Effluent)			
Acid Fraction	-	all parameters <25 ppb	all parameters <2 ppb
Neutral Fraction	all parameters <20 ppb	NA	NA
Sample No. 10 (Raw Water)			
Acid Fraction	all parameters <20 ppb	NA	NA
Neutral Fraction	all parameters <20 ppb	NA	NA

NA - not analyzed

TABLE C-6 ANALYTICAL RESULTS FOR MILL F (1981/82 toxics screening)

Sample/Fraction	EPS Atlantic Lab.	WTC Lab.	KER Lab.
Sample No. 11 (Raw Water)			
Acid Fraction	all parameters <20 ppb	NA	NA
Neutral Fraction	all parameters <20 ppb	NA	NA
Sample No. 12 (Screened Effluent)			
Acid Fraction			
phenol	33 ppb	65 ppb	
Neutral Fraction			NA
naphthalene	17 ppb	37 ppb	
di-n-butylphthalate	NA	246 ppb	
di-n-octylphthalate	NA	40 ppb	
bis(2-ethyhexyl)phthalate	NA	206 ppb	
Sample No. 13 (Final Effluent)			
Acid Fraction			NA
phenol	57 ppb	63 ppb	
Neutral Fraction			NA
naphthalene	14 ppb	21 ppb	
di-n-butylphthalate	NA	49 ppb	
di-n-octylphthalate	NA	16 ppb	
bis(2-ethylhexyl)phthalate	NA	74 ppb	

NA - not analyzed

TABLE C-7 ANALYTICAL RESULTS (Conventional Pollutants and Metals) FOR MILL A (1985/86 survey)

	Influent				Effluent			
Parameter*	Day 1	Day 2	Day 3	Mean	Day 1	Day 2	Day 3	Mean
pH (units)	10.9	12.3	12.4	11.9	9.5	10.1	11.4	10.3
COD	1090	1480	1080	1220	1070	1520	1140	1240
BOD	390	730	370	500	350	750	390	500
Total Suspended Solids	55	51	90	65	220	187	159	190
Total Dissolved Solids	990	2900	2800	2230	1770	1720	1780	1760
Total Non-ionic Surfactant	5.6	6.9	5.8	6.1	2.4	2.3	4.7	3.1
Phenols	0.066	0.065	0.082	0.071	0.027	0.031	NA	0.029
Ammonia - N	1.50	0.57	0.66	0.91	22	20	NA	21
Zinc	0.050	0.045	0.085	0.06	0.115/0.13	0.105	0.105/0.11	0.112
Cadmium	0.005	0.005	0.005	0.005	0.005/0.01	0.005	0.005/0.01	0.007
Manganese	0.03	0.03	0.02	0.03	0.099/0.10	0.08	0.08	0.09
Cobalt	0.01	0.01	0.01	0.01	0.01/0.02	0.01	0.01/0.02	0.01
Copper	0.060	0.040	0.055	0.05	0.145/0.14	0.12	0.120/0.13	0.13
Iron	0.62	0.34	0.34	0.43	3.5/3.6	3.0	3.3/3.2	3.3
Lead	0.07	0.01	0.01	0.03	0.07/0.04	0.10	0.06/0.04	0.07
Chromium	0.010	0.010	0.010	0.01	0.20/0.04	0.02	0.02/0.04	
Nickel	0.01	0.02	0.02	0.02	0.02	0.02	0.02/0.04	0.02
Mercury (µg/L)	0.65	0.65	0.72	0.67	0.95	0.79	0.90	0.88
Arsenic (µg/L)	11.0	2.5	2.0	5.2	14.0	11.0	6.5	10.5
96-h LC_{50}(%)	100	18	26	48	115	115	NA	115

NA = no sample available for analysis*; measured in µg/L unless otherwise noted.
Detailed sampling and analytical procedures are given in Appendix B.

TABLE C-8 ANALYTICAL RESULTS (Organic Priority Pollutants) FOR MILL A (1985/86 survey)

	Aeration Influent				Clarifier Effluent			
Compound	Day 1	Day 2	Day 3	Mean	Day 1	Day 2	Day 3	Mean
1,1,1-trichloroethane	ND	1.0	1.3	0.8	ND	ND	ND	ND
trichloroethylene	ND	Tr	1.1	0.5	ND	ND	ND	ND
toluene	93.0	26.5	37.8	52.4	6.4	2.4	2.0	3.6
tetrachloroethylene	3.2	12.0	18.2	11.1	Tr	Tr	Tr	Tr
ethyl benzene	986	50.7	69.6	152	18.9	2.4	1.8	7.7
1,4-dichlorobenzene	--	3.1	ND	1.6	3.3	Tr	--	1.9
phenol	Tr	30.4	Tr	-	Tr	Tr	Tr	--
naphthalene	--	6.6	Tr	3.8	14.2	4.1	--	9.2
di-n-butylphthalate	--	9.7	4.4	7.1	3.2	5.4	--	4.3
bis(2-ethylhexyl)-phthalate	--	6.6	13.9	10.3	19.5	6.6	--	13.1

Detailed sampling and analytical procedures are given in Appendix B.
Concentrations are in µg/L.

TABLE C-9 ANALYTICAL RESULTS (Conventional Pollutants and Metals) FOR MILL B (1985/86 survey)

Parameter*	Lagoon Influent				Lagoon Effluent			
	Day 1	Day 2	Day 3	Mean	Day 1	Day 2	Day 3	Mean
pH (units)	12.2	12.0	12.0	12.1	10.6	10.7	10.5	10.6
COD	1870/1940	1410	1180	1600	1510	870	920	1100
BOD	650	380	360	460	102	78	66	82
Total Suspended Solids	104	86	103	98	127	70	124/127	112
Total Dissolved Solids	2800	2400	2200	2470	2200	2300	2200	2230
Total Non-ionic Surfactant	4.5	7.5	7.4	6.5	4.0	3.6	1.9/2.2	3.2
Phenols	0.14	0.15	0.12	0.14	0.12	0.078	0.091/0.092	0.097
Ammonia - N	2.1	2.0	0.94	1.7	2.2	2.2	1.7	2.0
Zinc	0.16/0.24	0.34	0.24	0.26	0.34	0.22	0.28/0.32	0.29
Cadmium	0.01/0.02	0.01	0.01	0.01	0.01	0.02	0.01/0.02	0.02
Manganese	0.02/0.05	0.02	0.02	0.02	0.02	0.02	0.02/0.05	0.03
Cobalt	0.02/0.05	0.02	0.02	0.02	0.02	0.02	0.02/0.05	0.03
Copper	0.04/0.02	0.6	0.10	0.24	0.10	0.07	0.07/0.06	0.08
Iron	0.30/0.30	0.44	0.66	0.47	0.28	0.16	0.32/0.30	0.25
Lead	0.02/0.05	0.02	0.06	0.04	0.04	0.08	0.04/0.05	0.05
Chromium	0.01/0.02	0.01	0.04	0.02	0.01	0.02	0.02/0.02	0.02
Nickel	0.02/0.05	0.04	0.04	0.04	0.04	0.02	0.02/0.05	0.03
Mercury (µg/L)	1.78	0.34	1.36/1.03	1.10	0.68	0.96	0.82	0.82
Arsenic (µg/L)	24	5	5	11	5/4	4	4	4
96-h LC_{50}(%)	39	66	56	54	NL	100	96	99

Detailed sampling and analytical procedures are given in Appendix B.
NL - Not Lethal; *Measured in mg/L unless otherwise noted.

TABLE C-10 ANALYTICAL RESULTS (Organic Priority Pollutants) FOR MILL B (1985/86 survey)

Compound*	Lagoon Influent				Lagoon Effluent			
	Day 1	Day 2	Day 3	Mean	Day 1	Day 2	Day 3	Mean
1,2-dichloroethane	ND	1.5	ND	0.5	ND	ND	ND	ND
1,1,1-trichloroethane	ND	Tr	1.2	0.6	ND	ND	ND	ND
trichloroethylene	ND	ND	1.1	0.4	ND	ND	ND	ND
toluene	2.1	1.6	0.3	1.3	0.7	0.2	0.3	0.4
tetrachloroethylene	3.0	1.0	86	30	ND	ND	1.7	0.6
ethylbenzene	121	24.9	1.1	49	0.8	11.7	2.5	5.0
phenol	<15	<15	<15	<15	<15	<15	ND	<15
p-chloro-m-cresol	55.8	68.9	ND	<15	289.6	ND	232.6	174.1
pentachlorophenol	ND	<15	ND	<15	<15	ND	<15	<15
1,4-dichlorobenzene	Tr	1.2	ND	0.6	ND	ND	1.0	0.3
naphthalene	ND	1.1	1.6	0.9	ND	ND	ND	ND
di-n-butyl phthalate	3.2	3.5	2.9	3.2	3.5	10.1	4.8	6.1
bis(2-ethylhexyl)phthalate	4.5	10.9	6.4	7.3	15.9	7.2	11.0	11.4

Detailed sampling and analytical procedures are given in Appendix B; *concentrations are measured in µg/L
Tr - trace; ND - not detected

TABLE C-11 ANALYTICAL RESULTS (Pollutants in Lagoon Sludges) FOR MILL B (1985/86 survey)

	Lagoon Sludge	
	Near Influent	Near Effluent
Metal and Conventionals, µg/g (dry basis)		
Zinc	1440/1420	920
Cadmium	6/9	6
Maganese	78/78	58
Cobalt	10/12	9
Copper	149/151	149
Iron	5500/5300	4200
Lead	92/93	102
Chromium	154/147	220
Nickel	64/66	87
Mercury	0.070/0.075	0.050
Arsenic		
Total Kjeldahl N	8200	11 000/11 000
Moisture %	87.1	90.9
Volatile Organics, µg/L		
Dichloromethane	66.4	<1.0
Benzene	1.8	1.2
Toluene	14.4	15.0
Ethylbenzene	33.1	24.3
1,4-Dichlorobenzene	14.9	19.0
1,2-Dichlorobenzene	2.9	5.1
Acid Fraction Organics		
Phenol	3.9	2.4
Base/Neutral Organics		
Butyl benzyl phthalate	3.8	<2.0
Bis(2-ethylhexyl)phthalate	138.1	174.2

TABLE C-12 ANALYTICAL RESULTS FROM A SEPARATE SURVEY* FOR MILL B

Compound	Lagoon Influent				Lagoon Effluent			
	Day 1	Day 2	Day 3	Mean	Day 1	Day 2	Day 3	Mean
BOD	410	370	440	406	67	38	52	52
COD	1400	1200	1400	1333	490	600	1300	796
TSS	140	100	-	120	140	150	170	153
Oil and Grease	13	10	< 5	-	< 5	< 5	-	-
Fe	0.99	0.73	0.38	0.70	0.41	0.57	0.46	0.48
Cr	< 0.05	< 0.05	< 0.05	-	< 0.05	< 0.05	< 0.05	-
Cu	< 0.025	0.065	0.111	-	< 0.025	< 0.025	0.041	-
Ni	< 0.05	< 0.05	< 0.05	-	< 0.05	< 0.05	< 0.05	-
Pb	< 0.025	< 0.025	< 0.025	-	< 0.025	< 0.025	< 0.025	-
Cd	0.012	< 0.01	< 0.01	-	< 0.01	< 0.01	< 0.01	-
Zn	0.517	0.056	0.099	0.224	0.217	0.213	0.363	0.264

Concentrations are measured in mg/L
* Carried out by an EPS Regional Office in 1985

TABLE C-13 ANALYTICAL RESULTS (Conventional Pollutants and Metals) FOR MILL E (1985/86 survey)

Compound*	Main Effluent				Latex Effluent			
	Day 1	Day 2	Day 3	Mean	Day 1	Day 2	Day 3	Mean
pH (units)	7.0	6.8	7.1	7.0	7.6	7.9	7.2	7.6
COD	720	930/1100	1240	1000	14 800/20 000	21 000	12 900	22 900
BOD	220	500	230	320	168	260	160	196
Total Suspended Solids	17	24	30/28	23	1340	1080	4050	2160
Total Dissolved Solids	520	600	500/50	540	4500	6100	720	3770
Total Non-ionic Surfactant	105	120	78	101	0.1	0.2	0.2	0.2
Phenols	0.053	0.12/0.10	0.063	0.075	0.025	0.031	0.086	0.071
Ammonia - N	28	40	30	33	45	55	44/42	48
Zinc	0.01	0.03	0.05	0.03	0.05/0.03	0.20	0.10/0.05	0.10
Cadmium	0.01	0.01	0.01	0.01		0.05	0.05	0.05
Manganese	0.12	0.10	0.10	0.10	0.05/0.10	0.15	0.10	0.09
Cobalt	0.02	0.01	0.01	0.01	0.05	0.05	0.05	0.05
Copper	0.01	0.02	0.01	0.01	0.05	0.05	0.05	0.05
Iron	0.12	0.22	0.08	0.14	2.7	5.3	3.1/2.9	3.7
Lead	0.12	0.01	0.01	0.05	0.05	0.05	0.05	0.05
Chromium	0.02	0.01	0.01	0.01	0.05	0.05	0.05	0.05
Nickel	0.02	0.01	0.01	0.01	0.05	0.05	0.05	0.05
Mercury (µg/L)	0.04	0.02	0.01	0.02	0.1	0.3	0.1	0.02
Arsenic (µg/L)	--	--	--	--	10	10	10	10
96-h LC_{50} (%)	NL	NL	71	--	32	NL	--	--

Detailed sampling and analytical procedures are given in Appendix B; NL - not lethal
*all compounds measured in mg/L unless otherwise indicated

TABLE C-14 ANALYTICAL RESULTS (Organic Priority Pollutants) FOR MILL E (1985/86 survey)

Compound	Main Effluent				Latex Effluent			
	Day 1	Day 2	Day 3	Mean	Day 1	Day 2	Day 3	Mean
chloroform	3.1	2.4	Tr	2.0	2.2	3.1	6.1	3.8
1,1,1-trichloroethane	ND	0.9	ND	Tr	1.1	Tr	ND	Tr
bromodichloromethane	1.4	1.6	ND	1.0	ND	ND	ND	ND
toluene	Tr	Tr	ND	Tr	0.5	Tr	1.5	0.8
ethylbenzene	ND	ND	Tr	Tr	4.2	3.6	11.2	6.3
phenol	Tr	-	-	-	Tr	-	-	-
pentachlorophenol	-	19.3	Tr	-	-	-	-	-
1,4-dichlorobenzene	ND	ND	ND	ND	36.6	30.1	40.9	35.9
1,2-dichlorobenzene	ND	ND	ND	-	-	112.5	78.5	95.5
naphthalene	ND	ND	ND	-	-	14.6	5.3	10.0
fluorene	ND	Tr	ND	Tr	-	ND	2.4	1.2
di-n butyl phthalate	2.3	9.2	12.6	8.0	-	5.7	4.9	5.3
bis(2-ethylhexyl) phthalate	0.6	7.1	5.7	4.5	-	32.1	8.9	20.5

Detailed sampling and analytical procedures are given in Appendix B; Concentrations are measured in µg/L.
ND - not detected; Tr - trace

TABLE C-15 ANALYTICAL RESULTS (Conventional Pollutants and Metals) FOR MILL F (1985/86 survey)

Compound**	Bull Screen Composite*			Final Effluent Composite			
	Day 2	Day 3	Mean	Day 1	Day 2	Day 3	Mean
pH (units)	7.2	7.1	7.2	7.1	7.2	7.5	7.3
COD	490	290/300	360	650	440	440/390	500
BOD	154	75	115	300	200	132	210
Total Suspended Solids	48	62	55	61/70	70	40	59
Total Dissolved Solids	2000	2300	2150	2200	3300/3000	3200	2850
Total Non-ionic Surfactant	69/75	37/38	55	145	59	60	88
Phenols	0.052	0.030	0.041	0.133/0.131	0.053	0.054	0.080
Ammonia - N	19.2	18.0	18.6	31	15.7	19.2	22.0
Zinc	0.10/0.11	0.18	0.14	0.16	0.26	0.12	0.18
Cadmium	0.005/0.01	0.005	0.006	0.005	0.005	0.005	0.005
Manganese	0.02	0.05	0.035	0.04	0.04	0.04	0.04
Cobalt	0.01/0.02	0.01	0.01	0.01	0.01	0.01	0.01
Copper	0.020	0.035	0.028	0.055	0.035	0.045	0.045
Silver	0.01/0.02	0.01	0.01	0.01	0.01	0.01	0.01
Iron	0.38/0.39	1.12	0.075	0.68	0.85	1.34	0.96
Lead	0.01/0.02	0.03	0.02	0.05	0.06	0.07	0.06
Chromium	0.05/0.04	0.10	0.07	0.06	0.23	0.07	0.12
Nickel	0.01/0.02	0.01	0.01	0.02	0.02	0.02	0.02
Mercury (µg/L)	0.05	0.12	0.08	0.01	0.49	0.10/0.22	0.22
Arsenic (µg/L)	1	1	1	1	1	2	1
96-h LC_{50} (%)	75	100	88	45	NL	70	

detailed sampling and analytical procedures are given in Appendix B; NL - not lethal
* day 1 sample was omitted because of sampler malfunction; ** parameters measured in mg/L unless otherwise indicated

TABLE C-16 ANALYTICAL RESULTS (Organic Priority Pollutants) FOR MILL F (1985/86 survey)

Compound	Raw Wastewater				Equalized Wastewater			
	Day 1	Day 2	Day 3	Mean	Day 1	Day 2	Day 3	Mean
1,1,1-trichloroethane	Tr	2.1	5.3	2.6	Tr	2.1	ND	0.9
trichloroethylene	ND	ND	Tr	Tr	3.4	ND	ND	1.1
toluene	ND	0.6	1.4	0.8	0.5	0.5	1.5	0.8
tetrachloroethylene	ND	1.2	1.1	0.8	ND	3.4	1.5	1.6
ethylbenzene	6.5	7.7	38.2	17.5	Tr	1.8	23.8	8.6
1,4-dichlorobenzene	-	2.7	ND	-	ND	1.6	ND	-
naphthalene	-	5.2	2.3	2.9	15.4	5.3	5.1	8.6
fluorene	-	ND	ND	-	2.9	Tr	ND	-
di-n-butyl phthalate	-	7.1	29.8	13.4	318.1	5.9	148.9	158
bis(2-ethylhexyl)phthalate	-	96.4	24.4	48.7	71.3	25.4	23.7	40.1
phenol	Tr	Tr	Tr	Tr	26.9	26.4	-	17.8
2-chlorophenol	ND	Tr	ND	Tr	Tr	ND	Tr	Tr
2,4-dimethyl phenol	Tr	ND	15.9	Tr	Tr	ND	ND	Tr
2-nitrophenol	Tr	ND	ND	Tr	ND	ND	ND	-
2,4-dinitrophenol	Tr	ND	ND	Tr	Tr	ND	ND	Tr
pentachlorophenol	ND	Tr	ND	Tr	ND	ND	ND	-

Detailed sampling and analytical procedures are given in Appendix B; concentrations are measured in µg/L.
Tr = Trace Amount Detected - less than the detection limit (10 to 25 µg/L); ND - not detected

TABLE C-17 ANALYTICAL RESULTS (Conventional Pollutants and Metals) FOR MILL G (1985/86 survey)

Parameter*	Underwear Mill				Hosiery Mill			
	Day 1	Day 2	Day 3	Mean	Day 1	Day 2	Day 3	Mean
pH (units)	9.2	9.0	9.4	9.2	7.7	7.8	7.8	7.8
COD	980/970	720/670	220	630	390	490	450	440
BOD	117	76	57	83	69	85	60	71
Total Suspended Solids	108	152	55	105	71	49	69	63
Total Dissolved Solids	2090	3200	2200/2100	2480	1370	103	137	540
Total Non-ionic Surfactant	16	12	16	15	20	28	24/23	24
Phenols	0.049/0.055	0.052	0.015	0.040	0.24	0.24	0.20	0.23
Ammonia - N	1.00	0.54	0.32/0.30	0.62	17	26	26	23
Zinc	0.06/0.03	0.08	0.06/0.08	0.07	0.35	0.04	0.82	0.40
Cadmium	0.01/0.02	0.01	0.01/0.02	0.01	0.01	0.01	0.01	0.01
Manganese	0.02	0.03	0.01	0.02	0.02	0.03	0.02	0.02
Cobalt	0.01/0.02	0.01	0.02	0.01	0.01	0.01	0.01	0.01
Copper	0.10	0.03	0.03	0.02	0.07	0.05	0.06	0.06
Iron	0.15/0.09	0.28	0.21/0.18	0.02	0.07	0.10	0.05	0.07
Lead	0.06/0.02	0.07	0.01	0.04	0.01	0.01	0.01	0.01
Chromium	0.01/0.02	0.01	0.01	0.01	0.09	0.12	0.11	0.11
Nickel	0.01/0.02	0.01	0.01/0.02	0.01	0.01	0.01	0.01	0.01
Mercury (µg/L)	0.10/0.15	0.05	0.05	0.08	0.20	0.05	0.05	0.10
Arsenic (µg/L)	5/4	4	1/1	3	1	2	3	2
96-h LC_{50}(%)	59	61	100	75	43	17	66	42

Detailed sampling and analytical procedures are given in Appendix B; parameters measured in mg/L unless otherwise indicated.

TABLE C-18 ANALYTICAL RESULTS (Organic Priority Pollutants) FOR MILL G (1985/86 survey)

Compound	Underwear Mill				Hosiery Mill			
	Day 1	Day 2	Day 3	Mean	Day 1	Day 2	Day 3	Mean
1,1-dichoroethylene	ND	ND	--	ND	29.9	8.1	3.6	13.9
chloroform	34.0	1.7	--	17.8	448	221	81.7	250
1,1,1-trichloroethylene	ND	ND	--	ND	44.8	26.8	23.5	31.7
tetrachloroethylene	ND	ND	--	ND	1.7	1.4	Tr	1.2
phenol	--	15.0	21.5	12.2	--	58.6	46.1	34.9
2,4-dimethyl phenol	--	--	--	--	--	--	Tr	--
2,4-dichlorophenol	Tr	--	--	--	--	Tr	Tr	--
2-nitrophenol	--	--	--	--	Tr	Tr	Tr	--
naphthalene	ND	ND	ND	ND	19.9	7.2	3.5	10.2
di-n-butyl phthalate	5.1	ND	3.5	2.9	20.9	23.1	ND	14.7
bis(2-ethylhexyl)phthalate	4.9	4.0	9.6	6.2	3.2	4.7	0.5	2.8

Detailed sampling and analytical procedures are given in Appendix B; concentrations are measured in µg/L.
Tr - trace; ND - not detected

APPENDIX D
QUESTIONNAIRE USED IN THE 1985/86 SURVEY

TEXTILE INDUSTRY QUESTIONNAIRE

Company Name: _____

Plant Name: _____ Telephone No: _____

Address: _____ Contacts _____

_____

_____

_____

_____

_____

_____

_____

_____

A. MANUFACTURING

1. **Fibre/Yarns Used:**

_____ Wool
_____ Cotton
_____ Acetate

_____ Acrylic
_____ Modacrylic
_____ Nylon

_____ Polyester
_____ Rayon
_____ Other

2. **Production Processes:**

Slashing _____

Weaving:
_____ Broad
_____ Narrow

Non Woven:
_____ Chem. Bond
_____ Mech. Bond
_____ Therm. Bond

Tufting _____

Knitting:
_____ Circular
_____ Wrap

Dyeing:
_____ Yarn (space or skein)
_____ Piece
_____ Package

Preparation:
_____ Bleaching
_____ Washing
_____ Scouring
_____ Carbonizing
_____ Mercerizing

Finishing:
_____ Softening
_____ Waterproof
_____ Fireproof
_____ Tentering

Printing:
_____ Roller
_____ Screen
_____ Other

_____ Mildew Proof
_____ Wash & Wear
_____ Perm. Press
_____ Other

Acid _____
Cationic _____
Direct _____
Disperse _____
Other _____

Sulphur _____
Vat _____
Reactive _____
Developed _____

3. **End Products:**

Greige Goods:
_____ Knitted
_____ Tufted Carpets
_____ Woven

Dyed Yarns _____

Finished Fabrics:
_____ Knitted
_____ Tufted Carpets
_____ Woven

Other _____

4. **Volume Produced:** _____ (weekly avg.)
_____ (weekly max.)

5. **Operation:** _____ hours/week
_____ shifts/day

6. **Number of Employees:** _____

7. **Process Water Use:** _____

8. **All Other Water Use:** _____

9. **Intake Water Source:**

_____ Municipal
_____ Surface

_____ Subsurface
_____ Other

B. CHEMICAL AND DYES USED

Name	Functions

C. WASTEWATER

1. **Flow:**
   Average _____ (daily)
   Maximum _____ (daily)

2. **Waste Components:**

   _____ % Process _____ % Other
   _____ % Sanitary

3. **Effluent Quality:**

   BPD _____ mg/L
   CPD _____ mg/L
   TSS _____ mg/L
   Chromium _____ mg/L
   Phenol _____ mg/L
   Sulphide _____ mg/L
   Colour _____ ADMI
   pH _____ Units

   Temperature _____ °C
   Oil and Grease _____ mg/L
   Nitrogen _____ mg/L
   Phosphorus _____ mg/L
   Alkalinity _____ mg/L
   Other (describe) _____ mg/L

   Other (describe):
   _____ _____ mg/L
   _____ _____ mg/L
   _____ _____ mg/L

4. **Available Discharge Points:**

   Receiving Stream _____
   Municipal Sewer _____
   Other _____

5. **Monitoring:**

   Frequency _____
   None _____

6. **Existing Treatment Facilities:**

   Physical Pretreatment:

   _____ Equalization
   _____ Screening
   _____ Pre-aeration
   _____ Sedimentation

   _____ Flotation
   _____ Temperature Control
   _____ Other (describe)
   _____

   Biological Treatment:

   _____ Stabilization Basins
   _____ Activated Sludge
   _____ Trickling Filter
   _____ Aerated Lagoon

   _____ Anaerobic Pond
   _____ Denitrification
   _____ Other (describe)
   _____

   Advanced Treatment:

   _____ Carbon Absorption
   _____ Electrodialysis
   _____ Ion Exchange
   _____ Solvent Extraction

   _____ Reverse Osmosis
   _____ Foaming
   _____ Electrochemical Treatment
   _____ Other (describe)

D. SLUDGE

1. **Sources:**

   From wastewater treatment _____
   Other (specify) _____

2. **Volume/Weight Generated:**

   Average (daily, weekly or monthly) _____
   Maximum (daily, weekly or monthly) _____

3. **Contaminants (concentrations if known):**

   Heavy metals _____
   Chlorinated hydrocarbons _____
   Other (describe) _____

4. **Disposal:**

   _____ Impoundment
   _____ Dry combustion
   _____ Wet combustion
   _____ Land Disposal
   _____ Off-site
   _____ Other (describe) _____

E. SOLID WASTES

Type	Quantity	Contaminants	Disposal

F. AIR EMISSIONS

1. Types and Sources:

Oil mists		Sources	
Solvent vapours		Sources	
Particulates		Sources	
Other (describe)		Sources	

2. Monitoring:

Frequency
None

3. Control:

Control devices are used to control the emissions of
Brief description of the control device.

APPENDIX E
U.S. EPA BPT AND BAT EFFLUENT LIMITATIONS FOR THE TEXTILE INDUSTRY

D.1 Wool Finishing Subcategory

i) BPT Limitations, kg/1000 of fibre

	Daily Maximum	Monthly Average
BOD	22.4	11.2
COD	163.0	81.5
TSS	35.2	17.6
Sulphide	0.28	0.14
Phenols	0.14	0.07
Total Chromium	0.14	0.07
pH	6 to 9	6 to 9

ii) BAT Limitations, kg/1000 kg of fibre

	Daily Maximum	Monthly Average
COD	163.0	81.5
Sulphide	0.28	0.14
Phenols	0.14	0.07
Total Chromium	0.14	0.07

D.2 Woven Fabric Finishing Subcategory

i) BPT Limitations, kg/1000 kg of product

	Daily Maximum	Monthly Average
BOD	6.6	3.3
COD	60.0	30.0
TSS	17.8	8.9
Sulphide	0.20	0.10
Phenols	0.10	0.05
Total Chromium	0.10	0.05
pH	6 to 9	6 to 9

ii) BAT Limitations, kg/1000 kg of product

	Daily Maximum	Monthly Average
COD	60.0	30.0
Sulphide	0.20	0.10
Phenols	0.10	0.05
Total Chromium	0.10	0.05

D.3 Knit Fabric Finishing Subcategory

i) BPT Limitations, kg/1000 kg of product

	Daily Maximum	Monthly Average
BOD	5.0	2.5
COD	60.0	30.0
TSS	21.8	10.9
Sulphide	0.20	0.10
Phenols	0.10	0.05
Total Chromium	0.10	0.05
pH	6 to 9	6 to 9

ii) BAT Limitations, kg/1000 kg of product

	Daily Maximum	Monthly Average
COD	60.0	30.0
Sulphide	0.20	0.10
Phenols	0.10	0.05
Total Chromium	0.10	0.05

D.4 Carpet Finishing Subcategory

i) BPT Limitations, kg/1000 kg of product

	Daily Maximum	Monthly Average
BOD	7.8	3.9
COD	70.2	35.1
TSS	11.0	5.5
Sulphide	0.08	0.04
Phenols	0.04	0.02
Total Chromium	0.04	0.02
pH	6 to 9	6 to 9

ii) BAT Limitations, kg/1000 kg of product

	Daily Maximum	Monthly Average
COD	70.2	35.1
Sulphide	0.08	0.04
Phenols	0.04	0.02
Total Chromium	0.04	0.02

D.5 Stock and Yarn Finishing Subcategory

i) BPT Limitations, kg/1000 kg of product

	Daily Maximum	Monthly Average
BOD	6.8	3.4
COD	84.6	42.3
TSS	7.4	8.7
Sulphide	0.24	0.12
Phenols	0.12	0.06
Total Chromium	0.12	0.06
pH	6 to 9	6 to 9

ii) BAT Limitations, kg/1000 kg of product

	Daily Maximum	Monthly Average
COD	84.6	42.3
Sulphide	0.24	0.12
Phenols	0.12	0.06
Total Chromium	0.12	0.06